FISCAL YEAR 1985 DEPARTMENT OF ENERGY AUTHORIZATION
(High Energy and Nuclear Physics)

HEARING

BEFORE THE

SUBCOMMITTEE ON
ENERGY DEVELOPMENT AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

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FISCAL YEAR 1985
DEPARTMENT OF ENERGY
AUTHORIZATION

WEDNESDAY, FEBRUARY 22, 1984

House of Representatives,
Committee on Science and Technology,
Subcommitee on Energy Development and Applications,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:30 a.m., in room 2318, Rayburn House Office Building, Hon. Don Fuqua (chairman of the committee) presiding.

Present: Representatives Fuqua, Simon, Durbin, Mineta, Winn, Sensenbrenner, Schneider, Lowery, Bateman, and Carney.

Staff present: Dr. Harlan L. Watson, technical consultant; William T. Harvey, minority energy coordinator.

Mr. Fuqua. The subcommittee will be in order. This is the first in a series of eight hearings to be held by the Subcommittee on Energy Development and Applications concerning the fiscal year 1985 authorization request for the Department of Energy's civilian programs.

Today we begin our consideration of the basic research programs in the Department of Energy for which the administration has requested some $1.2 billion. These programs include high energy and nuclear physics, basic energy sciences, university research support and instrumentation, multiprogram general purpose facilities, and related activities. They support long-range frontier research performed at our national laboratories and universities.

The subject of today's hearings are the DOE's high energy and nuclear physics programs. These two programs have requested a total of $746.8 million, an increase of $105.6 million, or over 16 percent above the fiscal year 1984 appropriation.

Today, we will begin with Dr. Alvin Trivelpiece and Dr. Jim Leiss of the Office of Energy Research to discuss the administration's plans for fiscal year 1985. They will be followed by two panels, one on high-energy physics and the other on nuclear physics.

The first panel will be concerned with high energy physics and will include Prof. Maury Tigner, who will tell us about the ongoing superconducting super collider [SSC] reference designs activity; Dr. Leon Lederman, director of Fermilab, who will bring us up to date on the energy saver and Tevatron I and II projects; and Dr. Burt Richter, soon to be director of the Stanford Linear Accelerator

Center [SLAC], and to discuss the status of the Stanford linear collider [SLC].

The second panel will address the nuclear physics program and includes Dr. John Schiffer of Argonne, who is the current chairman of the DOE/NSF Nuclear Science Advisory Committee; Dr. Sam Austin of Michigan State University, who is a member of the recent NSAC panel on electron accelerator facilities; and Dr. Harry Holmgren of the University of Maryland and Dr. Jim McCarthy of the University of Virginia, who represent the Southeastern Universities Research Association. They will bring us up to date on the continuous beam electron accelerator facility proposed for construction at Newport News, Va.

[The prepared opening statement of Mr. Winn follows:]

STATEMENT BY HONORABLE LARRY WINN, JR.
ENERGY DEVELOPMENT AND APPLICATIONS SUBCOMMITTEE
HEARING ON
FY 1985 DOE AUTHORIZATION FOR HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS
FEBRUARY 22, 1984

THANK YOU, MR. CHAIRMAN. I, TOO, EXTEND A WELCOME TO DR. TRIVELPIECE, DOE'S DIRECTOR OF ENERGY RESEARCH, AND TO DR. LEISS. THE PROGRAMS FOR WHICH THESE SCIENTISTS ARE RESPONSIBLE TOTAL NEARLY 3/4 BILLION DOLLARS, UP FROM LAST YEAR'S APPROPRIATION OF $640 MILLION BY OVER 16 PERCENT. THIS IS A LOT OF MONEY, AND A LARGE INCREASE DURING A PERIOD OF STRINGENT BUDGET CONSTRAINTS. THIS COMMITTEE HAS ALWAYS PROVIDED SUPPORT FOR THESE BASIC, FUNDAMENTAL RESEARCH PROGRAMS AND RESULTS HAVE BEEN MOST GRATIFYING.

THE COMMITTEE'S INTEREST IN THE HIGH ENERGY AND NUCLEAR PHYSICS PROGRAMS PROMPTS SEVERAL OBSERVATIONS. FIRST, THE REQUESTED FY 85 FUNDING INCREASES SUBSTANTIATE THE ADMINISTRATION'S EARLIER DECISION TO BACK LONG-TERM, HIGH-RISK PROGRAMS WHICH INDUSTRY CANNOT FINANCE. SECOND, THIS FUNDING IS THE CORNERSTONE OF AMERICA'S RESEARCH PROGRAM. THIRD, THE AMOUNT OF MONEY INVOLVED AND THE MANNER IN WHICH IT IS DISTRIBUTED REQUIRE CONSTANT VIGILENCE SEEING THAT INEQUITIES DO NOT ARISE. SCIENCE, NOT POLITICS, MUST BE SERVED.

FOURTH, THE AMOUNT OF DATA BEING GENERATED BY THESE PROGRAMS MUST BE TREMENDOUS. TRANSFER OF THAT INFORMATION TO INDUSTRY REQUIRES A VERY HIGH PRIORITY.

DURING THIS PAST YEAR THE HIGH ENERGY AND NUCLEAR PHYSICS PROGRAMS HAVE MADE AN IMPACT ON THIS COMMITTEE IN AT LEAST TWO AREAS. IN YEARS PAST WE HAVE GIVEN STRONG ENCOURAGEMENT TO THE ISABELLE PROJECT, HAVING BEEN ASSURED BY DOE AND THE APPLICABLE SCIENCE GROUP OF ITS NECESSITY. WITH AN INVESTMENT OF $250 MILLION IN THE GROUND AND IN SUPPORTING RESEARCH, WE WERE SUDDENLY TOLD THAT WORK SHOULD BE STOPPED AND A BRAND NEW FACILITY STARTED. AND THE SAME SCIENCE GROUP SENT THE MESSAGE! I AM CERTAIN YOU REALIZE HOW UNSETTLING SUCH AN ABOUT-FACE CAN BE. WHAT SHOULD WE DO, START PROVIDING MORE MONEY, OR WAIT FOR ANOTHER SHIFT IN THE NOT-TOO-DISTANT FUTURE? ON THE OTHER HAND, WE ARE TOLD THE ISABELLE SITE MAY BE USEFUL FOR FUTURE NUCLEAR PHYSICS EXPLORATIONS. HOPEFULLY, INTELLIGENT UTILIZATION OF PREVIOUSLY FUNDED FACILITIES MAY BE THE CASE.

MORE RECENTLY, COMPETITIVE PROPOSALS WERE REVIEWED AND THE DECISION WAS MADE TO DESIGN, BUILD AND OPERATE A VERY POWERFUL ELECTRON ACCELERATOR. I HEAR THAT PRESENT PROJECT ESTIMATES EXCEED EARLIER PROJECTIONS. COULD LARGER EXPENSE LEAD TO ANOTHER SCIENCE GROUP TURNAROUND, SIMILAR TO THE ISABELLE SITUATION? I HOPE YOUR FIRST PRIORITY IS TO ESTABLISH COST AND THEN TO SEE IF ALL THE NUCLEAR PHYSICS PLANS CAN ACCOMMODATE THESE EXPENSE LIMITATIONS, NOT THE OTHER WAY AROUND.

I AM WELL AWARE THAT THE HIGH ENERGY AND NUCLEAR PHYSICS PROGRAMS RELY ON INCREASINGLY EXPENSIVE FACILITIES. I AM ALSO AWARE OF THE HEALTHY INTERNATIONAL COMPETITION WHICH HAS PUSHED OUR ENGINEERS AND SCIENTISTS TO TREMENDOUS DISCOVERIES. BUT NO TREND CONTINUES FOREVER. WILL FACILITIES BECOME EVEN MORE EXPENSIVE? WILL EACH NATIONAL GROUP CONTINUE TO GO IT ALONE? WILL GROUPS EXTERNAL TO GOVERNMENT PARTICIPATE? WHO WILL CONTROL OUR FUTURE PROGRAMS? THESE QUESTIONS MUST BE ANSWERED SOON BECAUSE I SEE CONFLICTS, GIVEN OUR BUDGET PROBLEMS AND COMPETITIVE PROGRAMS, BOTH SOCIAL AND SCIENTIFIC.

MR. CHAIRMAN, THANK YOU FOR THIS OPPORTUNITY TO SHARE MY INTERESTS IN THESE PROGRAMS. I LOOK FORWARD TO HELPFUL TESTIMONY FROM OUR WITNESSES.

Mr. FUQUA. Dr. Trivelpiece, we are very happy to have you here this morning, and we are pleased to hear from you.

STATEMENT OF DR. ALVIN W. TRIVELPIECE, DIRECTOR OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY, ACCOMPANIED BY DR. JAMES E. LEISS, ASSOCIATE DIRECTOR, OFFICE OF HIGH ENERGY AND NUCLEAR PHYSICS, U.S. DEPARTMENT OF ENERGY

Dr. TRIVELPIECE. Good morning, Mr. Chairman. It is a pleasure to be here. Members of the subcommittee, it is nice to see you.

With your permission, Mr. Chairman, I would like to have my prepared testimony submitted for the record.

Mr. FUQUA. Without objection.

Dr. TRIVELPIECE. Before turning to some of the specific aspects of the programs, I would like to make some general remarks. Basically, the fields we are talking about here today can be described as curiosity-driven fields. Probably curiosity is one of the more prevailing aspects of human characteristics, apart from the desire to survive. We have always been curious about what was in the next valley, across the desert, across an ocean, and so on. As the geographic frontiers have yielded to our curiosity, new frontiers have emerged to replace them, and these include things of space and time, things our forefathers would never have thought of pursuing.

To that extent, the curiosity that leads us to try to understand what the interior of an atom is and what the interior of a nucleus is and what the interior of the subparts of nucleus are, the quarks and gluons and things like that, are these new frontiers that we look at. This area of high energy and nuclear physics has received particular emphasis by this administration, and that emphasis has had good congressional support, and we believe that is a good thing to do. And there are many reasons why it is a good thing to do.

There is a tendency to focus on what might be referred to as some of the near-term competitive elements; namely, the interest in particular particles, the interest in competitive positions of the United States with respect to other countries, and so on. While that is interesting, I think it tends to overlook the area that really deserves the more important focus. That is, if you were a corporate officer in a company, and you were asking what you have been doing with your IR&D budget, your internal research and development budget, and has what you have been doing been good for the company, you would look back over 20 and 30 years in the United States and you would ask: How many things are there that we now enjoy that have their present activities and watershed events that took place in various areas of science, some of them in high energy nuclear physics?

It is quite staggering. It has been just plain good business that the United States has made a wise investment in various areas of science and technology, and these have paid off handsomely in terms of our gross national product and various areas of our balance of trade. I think there is a tendency to overlook the past investment and focus more on the near-term things, and I believe it is important to remind ourselves from time to time that this has been just plain good business in the strictest sense of the word. The return to the Federal Treasury today, through taxes and other returns and balance-of-trade benefits has been excellent.

The national need continues. I know you have heard other testimony on this, but the administration is interested in trying to emphasize those things that will improve the number of talented people we have to address the various problems that the country has. And in so doing, in choosing research, we should choose areas in which those that we chose to engage in we can be excellent, that excellece should be one of the hallmarks of our activities. One of the other things I have also testified on in past years has been the need for an improvement in the partnership between Government and Government laboratories and university and industry. I think we are making considerable progress on that, although this program does not necessarily involve the industrial component, but some of the future plans it will engage in may.

I think the recognition of these elements has occurred in a rather interesting way that I want to call attention to in these opening remarks. The last 2 years have seen a couple of events take place. These were the seven countries that make up the economic summit countries, plus the European Community. They met in Versailles and they since met here in the United States in Williamsburg, and there is a meeting planned for London sometime in May or June of this year. The heads of state, in gathering, recognized the role of science and technology and its importance to the economic health of members states that make up the economic summit countries.

The United States has a role in several of these areas of science and technology, and the Department of Energy in particular has a role in breeder and in the high energy physics program, as well as the fusion program. We are at a new threshold, I think, in connection with some of these projects in which it will be necessary to involve ourselves in international collaboration and cooperation in ways that have not been necessarily characteristic of the past, although these programs are excellent examples of international cooperation, in that the scientists in the United States and the scientists from abroad share and utilize facilities in a very beneficial and cost-effective way.

The prospect of some larger facilities I think brings home even more clearly the need to begin cooperative planning early on.

This has been a rather busy year from the time we appeared before you last year. Just at this time last year, two new particles, the W plus and minus, had been reported and talked about a little bit here. Since then, the so-called Z-zero particle has been discovered, and of course it is not a question of the particle-of-the-year contest. The discovery and confirmation and verification of the characteristics of those particles is extremely important because it confirms certain aspects of theoretical predictions that had been quite an extrapolation of known knowledge at that point. It is very important that those events took place, and it gives great confidence in some of the theoretical models that have been established to describe how fundamental particles behave and what the forces are that influence their behavior.

The High Energy Physics Advisory Panel was another event that took place last year, or activities which they engaged in caused a certain number of events to take place, I should say. We asked them to outline for us what the important elements in the program were and what should be the emphasis of the program. As you are aware, they recommended that we not continue the Isabelle, the CBA project at Brookhaven. There were hearings that were held sometime in the October and November time frame of last year, and we discussed it in some detail.

By way of a progress report, we have made the necessary reprograming requests and notifications that we indicated we would, and we have now taken the steps to put the tunnel into a mothball state so that whatever future purpose it might serve can be done without further modification.

One of the things that the High Energy Physics Advisory Panel stressed was the need to begin the early work toward a device which they have named the superconducting super collider, and that was to be a 20 Tev proton collider. We have engaged in some work there, and the funds that were reprogrammed in part from the ISABELLE activity and in part from other areas have gone into some activities this year which you will hear some more about from the other witnesses in the panels.

But at the moment, the department is engaged in a reference designs activity. Secretary Hodel has insisted, and I think rightly so, that before we proceed with this further, we have a good idea of the preliminary cost. He is requesting that we go through this reference designs activity for which we have requested the reprogramming.

As you know, one of the concerns of that activity is the cost, and there are cost-reducing design efforts now being undertaken by scientists and engineers at the laboratory. One of the other elements that will come up, which the preliminary work is now engaged in, is the consideration of what constitutes the site criteria. What would be necessary in order for there to be an adequate operating site. As well, we are looking within the department into what type of interim management arrangements we think would be appropriate in order to conduct this business during the next several years during which the cost and design are refined.

This year has also seen a remarkable event in the operation of the world's first superconducting accelerator, that is the Fermilab. It has gone into operation, and it is a remarkable achievement. They have done so in a rather expeditious way, and only recently the energy of the beam was increased to a world's record level of 800 GeV. There is a dedication ceremony that will be planned later this year, and I am sure Dr. Lederman will extend an invitation to members to attend that, and we hope that you can. It will be a good ceremony sometime in April.

This year also saw the groundbreaking ceremony for the Stanford Linear Collider. That was a project we had requested construction funds for last year, and I think it is up and running.

One of the things we have chosen to emphasize in the high energy physics program is the need to operate the facilities at a level that is consistent with the investment that has been made in these facilities. There has been a tendency to cut the corners a little bit on operations over the years in order to emphasize some of the construction things. This is a trade-off and a balance problem that always comes up.

We have chosen to try to increase the operating levels, and there are comments in the prepared testimony about the exact percentages of it. I think that rather than focus on the percentages, it is more important to look at the trend. The trend is that the operating level of the major high energy physics facilities has been increasing.

One of the elements in the budget is an increase in capital funding requests. I think this is very consistent with the needs of this program. To build the accelerators, to do the theory, to develop the capability of reducing the data and so on, it is important but it is also important to recognize that the detectors that are used in the course of this research are themselves complicated pieces of equipment and require considerable funds in order to bring them up to levels that will make them capable of providing the data needed to unravel the various questions.

On high energy physics, I would comment that there is a tendency to overlook the fact that these facilities are operated by the department primarily for use by university scientists. Some 75 percent of the people who use these are faculty members and scientists at various academic institutions. This is really an integral part of the U.S. educational enterprise, and keeping score of where graduate students are supported and so on, this does not usually get taken into account as one of the university activities. It is not scored normally as part of the university support which the department provides.

Turning to nuclear physics, the Nuclear Sciences Advisory Committee, whose chairman you will hear from later, made some recommendations concerning the next most important steps that they see for nuclear science. Without getting into the technical details, what they have recommended is a continuous electron beam accelerator facility, which is called CEBAF. It is at 4 GeV energy, and its purpose is to look into some of the interior characteristics of nuclei in ways that have been heretofore impossible.

During the summer, Secretary Hodel selected the Southeastern Universities Research Association to be the contractor, and since the President's budget has been sent to the Hill, we have requested some reprogramming of 1984 funds to begin activities on the site for some architects and engineers and preliminary site preparation activities.

Last year, we made some deliberate attempts to try to improve the condition at universities with respect to equipment, and recognizing that equipment has been allowed to deteriorate at many of the academic institutions in areas where Government support is appropriate. To that extent, in the nuclear physics area, we chose to emphasize an upgrading of the Yale and Washington Universities accelerators, and we are pleased that is continuing, and that work will be completed this year.

At the Argonne National Laboratory, the Atlas accelerator, which is a superconducting accelerator—not in the magnets that guide the beam but rather in the resonant cavities that are used to accelerate the particles—that is operating in a preliminary way. The use of superconducting radio frequency cavities to accelerate these particles is an important step because it reduces the amount of power that is needed, as well as improving the versatility of the beams that are used by the physicists making experiments in this area.

The Nuclear Science Advisory Committee also recommended on a longer-term basis that we begin the early consideration and planning for a machine that would provide the opportunity to permit heavy ions to collide in a way that would let us study some aspects of nuclear interiors that is not otherwise possible also.

In the case of the nuclear physics program, the operating budgets are down. We recognize this is a problem. It has been necessary to make some compromises in terms of operating and construction. However, I think the balance is still right and that the program is in a good state to proceed with the activities that are planned for it.

With that, Mr. Chairman, I would conclude my introductory remarks, and I will be glad to answer any questions.

[The prepared statement of Dr. Trivelpiece follows:]

Statement of Alvin W. Trivelpiece

Director of Energy Research

Department of Energy

before the

Subcommittee on Energy Development and Applications

of the

House Science and Technology Committee

February 22, 1984

Mr. Chairman and Members of the Subcommittee:

It is a pleasure to appear here today to present the FY 1985 budget request for the High Energy and Nuclear Physics (HENP) programs. The High Energy and Nuclear Physics request is shown in Table 1 which gives the total ER budget request for FY 1985. This budget request reflects the goals and strategies set out in the Fourth National Energy Policy Plan (NEPP-IV), published in October 1983. As stated in NEPP-IV, the goal of our national energy policy is to foster an adequate supply of energy at reasonable costs. The strategies for achieving this goal are: (1) to minimize Federal control and involvement in energy markets while maintaining public health and safety and environmental quality, and (2) to promote a balanced and mixed energy resource system. NEPP-IV also stresses the need to expand our base of scientific knowledge and notes that, "we are better off as human beings and as a Nation for having increased our understanding of nature and matter."

The High Energy and Nuclear Physics programs contribute to DOE's implementation of NEPP-IV's goal and strategies by supporting the most basic long-term scientific research--that aimed at improving our understanding of the fundamental constituents of matter and energy and the basic forces in nature that control the interactions among those constituents. This research advances the frontiers of our scientific and technical knowledge and provides fundamental building blocks for technological innovation. Because the research is long-term and not initially applicable to any given energy technology, the private sector has no incentive to support research in high energy and nuclear physics.

Table 1
Office of Energy Research
Summary by Program
($ in millions)
Budget Authority

	FY 1984 Estimate	FY 1985 Request
General Science & Research		
High Energy Physics	$480.0	$561.0
Nuclear Physics	159.0	183.6
General Science Program Direction	2.2	2.2
Subtotal	641.2	746.8
Energy Supply - R&D a/		
Basic Energy Sciences	$337.3	$419.5
Magnetic Fusion Energy	470.8	483.1
Biological & Environmental Research	183.9	189.1
Energy Research Analyses	2.9	3.0
University Research Support	5.5	9.2
University Research Instrumentation	4.0	6.0
Multiprogram General Purpose Facilities	42.1	39.0
Advisory & Oversight Program Direction	3.4	2.9
Policy and Management	1.3	0.5
Subtotal	$1,051.2	$1,152.3
Total ER	$1,692.4	$1,899.1 b/

a/ These programs are the subjects of separate hearings.
b/ These estimates reflect $15.6 million for savings resulting from FY 1985 management initiatives.

The Department's High Energy and Nuclear Physics programs have long been important to the vitality and development of science and technology in the U.S. Through the efforts of its practitioners, this research has made vital contributions not only to energy resource development but to education, health, industry and national defense. Significant contributions to the economic growth and prosperity of the Nation have come directly from the results of the research, from technological spinoffs, and from the training of tomorrow's scientists through the involvement of university graduate students in carrying out the research. Through technology transfer, these ideas and people have made contributions in a variety of industries including medical instrumentation, control and instrumentation of industrial processes, and the production of nuclear energy. In FY 1985, the HENP programs will continue to increase our fundamental understanding of the physical world and assure that research results are available to those who might use them.

In this century, scientific investigation has focused on understanding the relationships among ever more fundamental constituents of matter, with the research frontier moving from atoms, to nuclei, to the constituents of nuclei (protons and neutrons) and recently to even more elemental subnuclear constituents, somewhat whimsically referred to as quarks and gluons. The Department funds approximately 90% of the High Energy and Nuclear Physics research that is carried out in the United States. The National Science Foundation supports the rest in a joint endeavor with the Department.

The High Energy and Nuclear Physics programs are closely related in terms of goals, the types of facilities and equipment used to reach these goals and the impact that research in one program has on the other. Although the two programs have related goals, they have quite different research emphases.

The Nuclear Physics program strives to attain a better understanding of the structure and properties of the atomic nuclei that comprise the cores of the atoms and the forces that govern their behavior. It also seeks to determine how the quark substructure of protons and neutrons influences the make-up and characteristics of nuclei (i.e., how do quarks act when they are imbedded in nuclei?). High Energy Physics research seeks to understand the nature and relationships among the fundamental forces of nature and to understand the ultimate structure of matter in terms of the properties and interactions of its basic constituents.

Although the focus of each of the programs is somewhat different, most experiments in both the High Energy and the Nuclear Physics programs depend on large experimental facilities that accelerate beams of particles to collide with stationary targets or other moving particle beams. These are required to probe the properties of atomic nuclei, in the case of Nuclear Physics, or to study elementary particles such as quarks in the case of High Energy Physics. The primary experimental technique used in both programs is to analyze the results of the collisions. Many entirely new forms of matter can be created in these collisions by means of a series of energy-to-matter transformations which are described by Einstein's famous formula, $E=mc^2$. The study of these dynamic phenomena then reveals the properties of the underlying building blocks and basic forces involved. In general, as the particles studied become more elementary, their component parts are bound together more tightly. Thus, larger, more powerful and complex accelerators, detectors and supplementary equipment are required to carry out the research.

Although progress in High Energy and Nuclear Physics is dependent on the availability of these forefront accelerator and colliding beam facilities, as well as on the sophisticated detectors that record the effects of particle collisions, these advanced facilities are only one facet of the program. Progress in both High Energy and Nuclear Physics features a continuing interplay of advancements in experiment, theory and technology. HENP experiments are done at the very forefront of theoretical and technical knowledge, and the range of experiments possible is determined by available technology. Physicists frequently have to invent unique equipment and technology to carry out the experiments of greatest importance. Great strides in technology advancement are now coming at the same time that our understanding in both fields of research is growing rapidly. Together, these advancements provide a clear view of the kinds of new experimental facilities that will be required to take advantage of the growing number of successes in recent years.

The large scientific facilities supported by the HENP programs are available to qualified scientists for experimental research on the basis of the merit of their scientific proposals. Approximately 75% of the research in high energy physics is done by university-based scientists who usually form collaborations with scientists from other universities or from DOE's laboratories. Typically, proposals from university and laboratory user groups for accelerator research time are evaluated by scientific program advisory committees which recommend for selection those proposals with the greatest scientific promise. The High Energy Physics program operates almost exclusively in this mode, while Nuclear Physics, in addition to national facilities, also supports dedicated accelerator facilities located on the campuses of four leading universities (Duke, Yale, Texas A&M, and the University of Washington) where research is primarily conducted by resident researchers and graduate students. To complement, interpret, and guide the experimental work, each program supports a vigorous theoretical research effort at universities and at the national laboratories.

HIGH ENERGY PHYSICS

Considerable progress has been made in recent years toward improving our understanding of energy and matter and their most elemental transformations. We have not only identified a growing number of particles, but have seen how they relate to one another and how they can be transformed during collisions with other particles in accelerator experiments. A long-standing goal of high energy physicists is to understand these diverse and complex phenomena by formulating a theory which would encompass all of the interactions of matter and energy revealed by their research. These "unified" and "grand unified" theories, as physicists call them, hypothesized over the last 10 years, imply that the diversity existing in the universe today may have evolved from a single force, or process, that existed only when the universe was formed some 20 billion years ago.

These theories aim at linking together, or unifying, the four known fundamental forces of nature and identifying the basic constituents, or building blocks, of matter. The electromagnetic force describes how atoms and molecules are formed and is the cornerstone to understanding chemistry, electronic communications and biological processes. The weak nuclear force describes processes such as the radioactive decay of nuclei. The strong nuclear force helps describe how the nucleons, and thus all nuclear matter, are held together. The gravitational force, perhaps the most familiar of the four forces of nature, explains such things as why rocks fall and planets move in their orbits. The basic constituents of matter are presently hypothesized to consist of "quarks and leptons." Quarks are thought to be the constituents of nuclear matter. Leptons are weakly interacting particles, like the electrons, muons, and neutrinos.

Recent research results have led to an increasingly better understanding of the forces of nature. That understanding is defined in theories that indicate that the weak nuclear and the electromagnetic forces are actually different forms of a single force--referred to as the electroweak force. Two U.S. physicists shared in the 1979 Nobel Prize for work on this unification. The 1980 Nobel Prize in Physics was also awarded to two U.S. physicists for work that is expected to contribute to unification theories that encompass the strong nuclear and electroweak forces. Eventually, it is postulated that the gravitational force will be incorporated into a super unification theory, bringing all of the basic forces into a unified framework.

Among the predictions of the new theories is that protons, which were previously thought to be absolutely stable, do eventually decay; and that neutrinos, among the most abundant particles in the universe and previously thought to be massless, could instead have a small mass. Special emphasis in the experimental program is focused on testing these and other predictions of the unified theories.

Advances in experimental research during 1983 were highlighted by the observation at CERN in Geneva, Switzerland of the long-sought particles (called "W" and "Z") which are the carriers of the weak nuclear force. The discovery was made by an international team of researchers which included research scientists from the U.S. The observation of these particles, each of which is almost a hundred times heavier than a proton, was critical to the theory of unification of the weak and electromagnetic forces which had predicted their existence. Significant progress has also been achieved in precision measurements of the results of collisions of high energy electrons and positrons at the Positron-Electron Project (PEP) and the Stanford Positron-Electron Asymmetric Ring (SPEAR) facilities at the Stanford Linear Accelerator Center. Teams of university and laboratory scientists have measured a surprisingly long lifetime of a particle thought to contain one of the heaviest quarks, and have observed the presence of new states of matter resulting from decays of particles containing "charmed" quarks. The long lifetime, interesting in itself, has also given new clues in the search for even heavier particles. One interpretation for the new states observed is that they could be made up entirely of the gluons that are thought to be the carriers of the strong nuclear force.

The experimental work in High Energy Physics is carried out primarily on the high energy accelerator and colliding beam facilities operated by the Department. In FY 1985, these include: the 30 GeV (billion electron volts) proton synchrotron, called the Alternating Gradient Synchrotron (AGS), at Brookhaven National Laboratory (BNL); the 1000 GeV superconducting magnet proton synchrotron at Fermi National Accelerator Laboratory (Fermilab); and the 32 GeV linear electron accelerator at the Stanford Linear Accelerator Center (SLAC). SLAC also has two electron-positron colliding beam facilities for which the linear accelerator acts as the injector: the Stanford Positron Electron Asymmetric Ring (SPEAR) (4 GeV x 4 GeV) and the

Positron-Electron Project (PEP) (15 GeV x 15 GeV). Each of these DOE accelerator centers provides a unique set of experimental capabilities, complementary to the others. As an ensemble they provide capabilities essential for a comprehensive forefront national research program in high energy physics. A major part of High Energy Physics funding is required to develop, maintain and operate the major accelerator and detector facilities at these laboratories. These facilities are shown in Figures 1-6.

Before I discuss the budget request, I would like to report a major technological achievement during this last year. The Energy Saver, the world's first high energy accelerator using superconducting magnets, has been brought into successful operation at Fermilab. The last superconducting magnet was installed in March 1983 and by early July the beam had been accelerated to 512 GeV, a world record energy. The accelerator is presently providing beam to experiments at 400 GeV. This energy will be increased to approximately 700 GeV in the near future. In FY 1985 the accelerator is expected to operate at energies near 1000 GeV. This is truly a major step in the development of superconducting magnet technology.

FY 1985 High Energy Physics Budget Request

The FY 1985 request for the High Energy Physics program is $561.0 million, which consists of $381.6 million for Operating Expenses, $65.4 million for Capital Equipment and $114.0 million for Construction (Table 2).

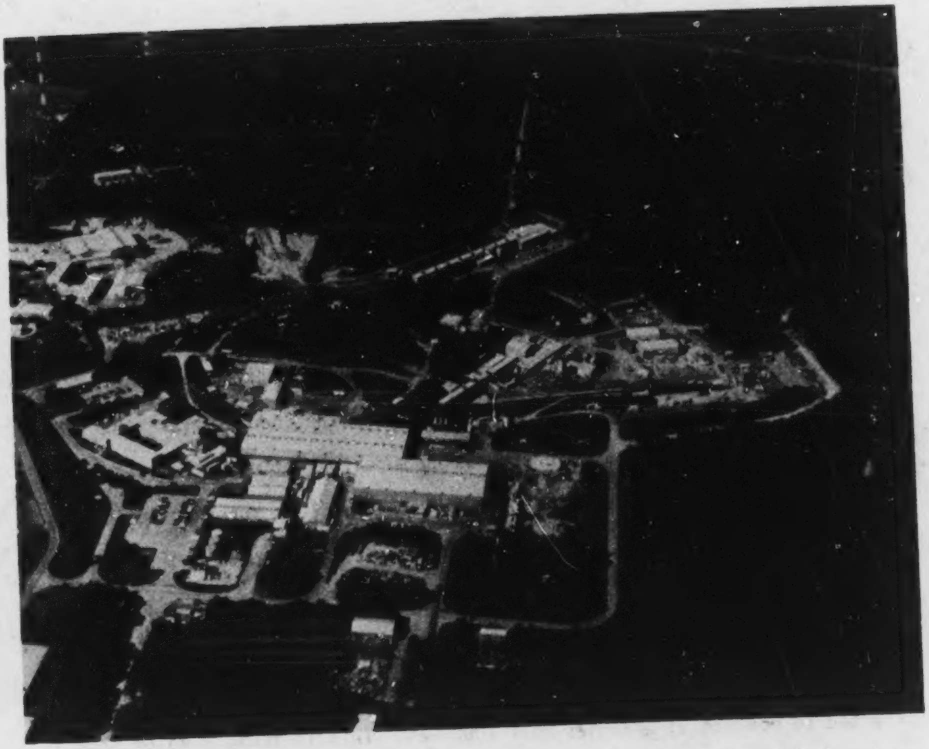


FIGURE 1.—Alternating Gradient Synchrotron—Brookhaven National Laboratory

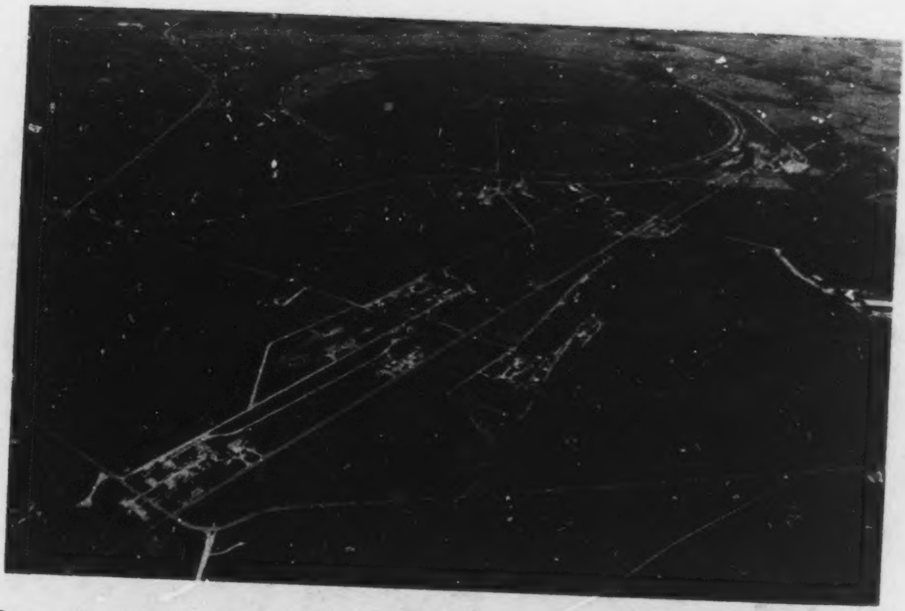


FIGURE 2.—Fermi National Accelerator Laboratory (main ring of accelerator system at top of photo; central laboratory at right of main ring; the Neutrino Laboratory in the foreground; Meson Laboratory to the right; Proton Laboratory to the far left)

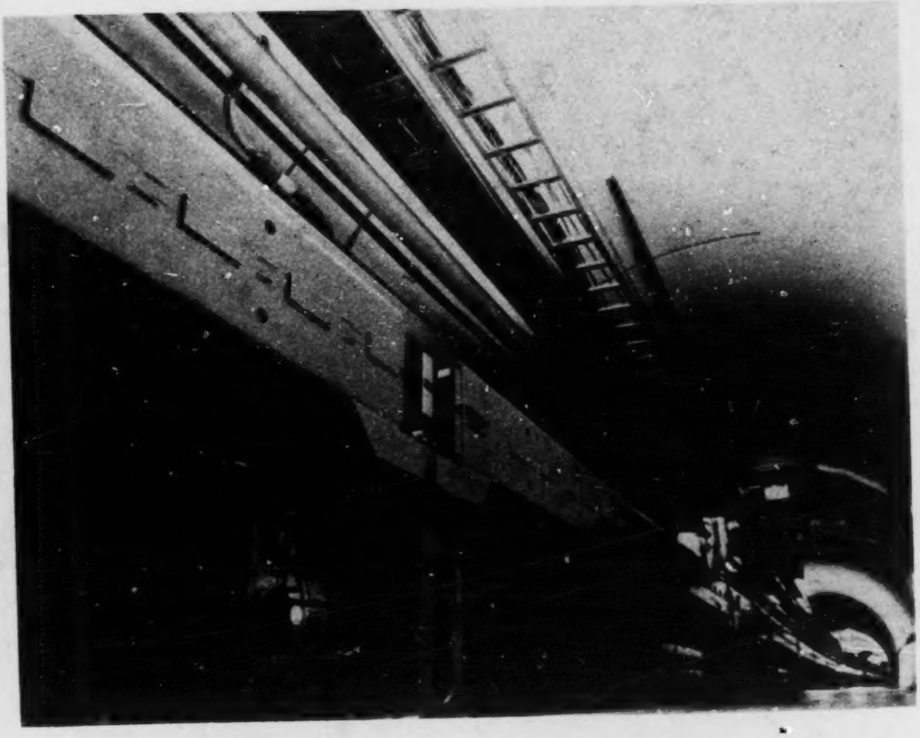


FIGURE 3.—Energy Saver Magnets—Fermi National Accelerator Laboratory

FIGURE 4.—Stanford Linear Accelerator Center

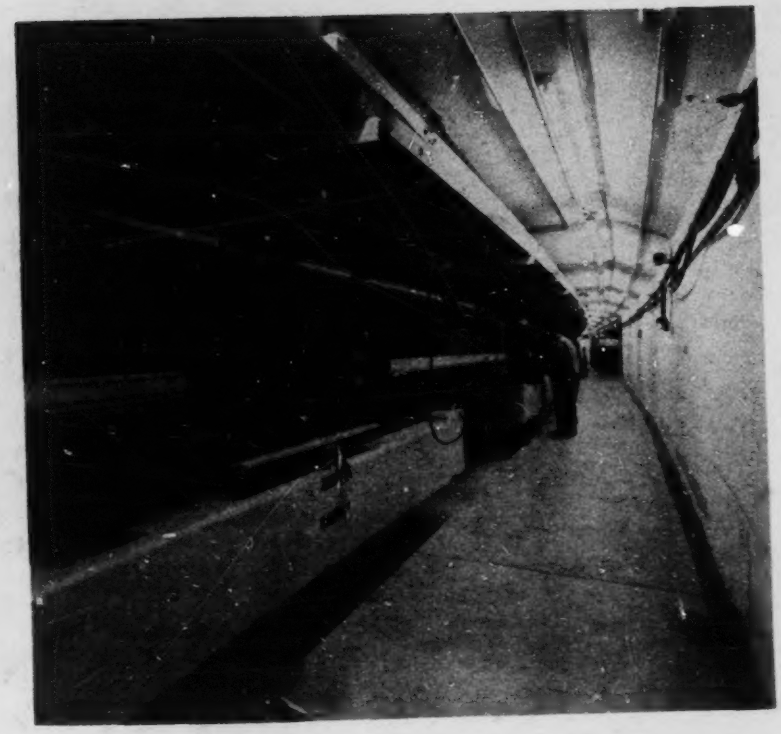


FIGURE 5.—PEP Storage Ring—Stanford Linear Accelerator Center

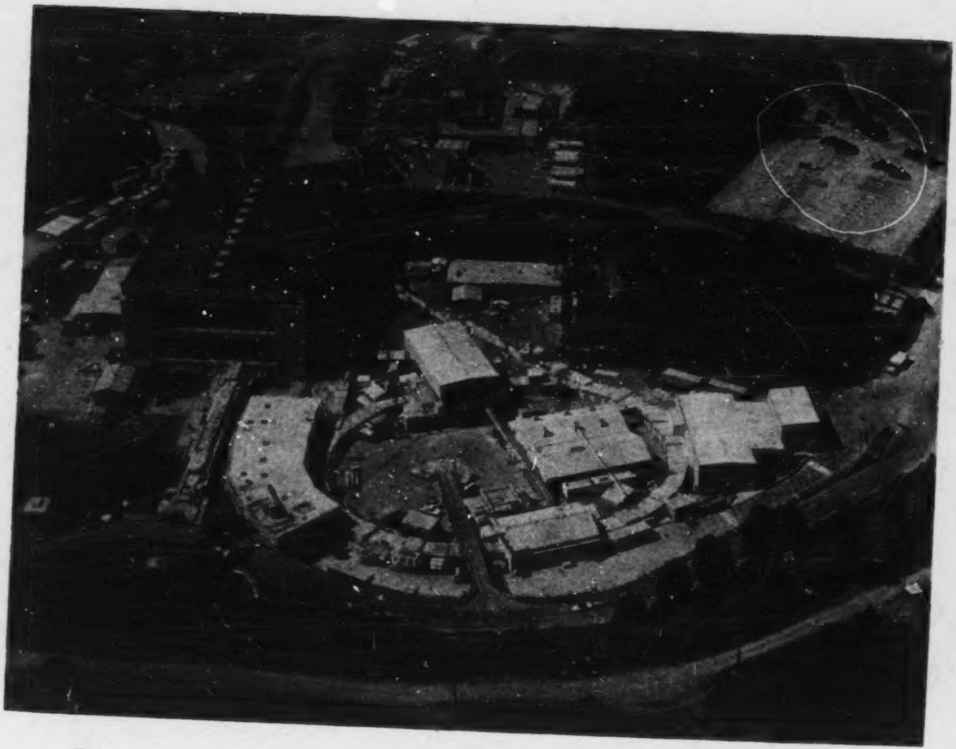


FIGURE 6.—SPEAR Storage Ring (and research areas)—Stanford Linear Accelerator Center

Table 2
High Energy Physics
Budget Authority
($ in millions)

	FY 1984 Estimate	FY 1985 Request
Operating Expenses		
Physics Research	$ 99.5	$107.7
Facility Operations	161.0	182.1
High Energy Technology	82.0	91.8
	$342.5	$381.6
Capital Equipment	51.5	65.4
Construction	86.0	114.0
Total High Energy Physics	$480.0	$561.0

The FY 1985 request for Operating Expenses will permit an overall utilization level of the High Energy Physics accelerator facilities at about 55%, somewhat above the FY 1984 level. The request also provides continuing support for university and laboratory based research groups including accelerator experiments, non-accelerator experiments, and theoretical research. There will be continuing accelerator R&D activities at Fermilab and SLAC in support of ongoing construction projects.

The FY 1985 request for Operating Expenses also will provide for preliminary R&D studies for the next generation particle accelerator designated the Superconducting Super Collider (SSC). Construction of such a new facility was recommended by the High Energy Physics Advisory Panel (HEPAP). Specifically, HEPAP recommended as highest priority "the immediate initiation of a multi-TeV high luminosity proton-proton collider project with the goal of physics experiments at the earliest possible date." The SSC would provide a research capability in an unexplored domain for which there are no existing or planned facilities anywhere in the world and in which there is strong expectation of major research breakthroughs.

The Department has evaluated the HEPAP recommendation and decided to initiate an R&D program at various locations in FY 1984 to investigate key issues associated with construction of such an accelerator. The major emphasis in FY 1984 is on superconducting magnet R&D and on developing a reference design with a cost estimate based on credible assumptions about possible achievements in the R&D program. In FY 1985, preliminary R&D for the SSC will focus on development and evaluation of technical options for magnets and other accelerator components, development and validation of cost saving designs and fabrication techniques, consideration of accelerator design alternatives and trade-offs, and cost optimization studies.

The FY 1985 Capital Equipment request of $65.4 million provides a substantial increase above the FY 1984 level in order to meet some of the major needs associated with implementation of research programs using the major new research capabilities being provided by the Tevatron I and Tevatron II projects at Fermilab and the Stanford Linear Collider (SLC) at the Stanford Linear Accelerator Center. This increase in Capital Equipment funding in FY 1985 is essential for the effective utilization of the U.S. High Energy Physics facilities and for the health of the U.S. High Energy Physics program for the remainder of the 1980's.

The request for Capital Equipment gives priority to Fermilab for the new secondary beam lines and detector systems needed to implement the 1000 GeV research program associated with the Tevatron II fixed target program and for work on detectors needed for the Tevatron I proton-antiproton colliding beam research program. Priority is also given to SLAC for work on detectors for electron-positron colliding beam research at the SLC; to the university program to meet the needs of experiments at the U.S. laboratories and at the Large Electron Positron (LEP) facility at the CERN Laboratory in Geneva, Switzerland; and for non-accelerator experiments.

In addition to programmatic equipment needs, the High Energy Physics program provides for the general purpose equipment requirements for all DOE programs at the Brookhaven National Laboratory.

A total of $114.0 million in Construction funding for High Energy Physics projects is requested in FY 1985. The projects are listed in Table 3. A major portion of this request is for continued construction of the Stanford Linear Collider ($60.5 million). The primary goal of this project is to develop and demonstrate the technical feasibility of using linear accelerators with precisely controlled, high intensity and highly focused beam pulses to provide high rates of electron-positron collisions at energies far beyond those that will be affordable for circular colliders. SLC also will give U.S. physicists early access to the important physics which can be studied with copious production of the Z^0 particle.

The request also provides for completion of the Tevatron II project at Fermilab ($12.0 million) and continuation of Tevatron I ($21.3 million) at Fermilab.

Funds are requested for Accelerator Improvement Projects ($10.0 million), which are critical on an annual basis to maintain the scientific effectiveness and the operating reliability and efficiency of the accelerator and colliding beam facilities. The request also provides for an improved level

Table 3
High Energy Physics
Budget Authority
($ in millions)

Construction	Prior Years	FY 1985 Request	TEC	Completion Date
Tevatron I (81-E-218)	$ 54.1	$ 21.3	$ 82.5	FY 1986
Tevatron II (82-E-206)	37.8[a]	12.0	49.0	FY 1985
Stanford Linear Collider (84-ER-133)	34.3[b]	60.5	112.0	FY 1986
Accelerator Improvement Project (85-R-100)	N/A	10.0	N/A	FY 1987
General Plant Projects (85-R-101)	N/A	10.2	N/A	FY 1987
Total Construction		$114.0		

a/ Includes $0.8 million for PE&D
b/ Includes $2.3 million for PE&D

of General Plant Projects ($10.2 million). Within the GPP request, emphasis is placed on the needs at BNL, since the High Energy Physics program provides funding for the general purpose needs of all DOE programs at this laboratory.

NUCLEAR PHYSICS

Nuclear knowledge, techniques, instruments, and applications pervade American society. These serve as the basis for our national defense strategy, for therapeutic and diagnostic medical applications, for the generation of electricity with nuclear reactors (fission now and fusion in the future), and for a large and diverse array of applications in industry. The behavior of nuclei and nuclear matter determine the physical properties of our universe--from its creation from a primordial "soup" of energy and elementary particles, to the reactions which power our sun, to the makeup of our planet. Thus, basic nuclear research is both a central component in our Nation's long-term investment in its technological future and an essential foundation to any basic understanding of the world about us.

The Nuclear Physics program is a comprehensive program of interdependent experimental and theoretical investigations of atomic nuclei. We seek to understand the interactions, properties, and structures of atomic nuclei and nuclear matter at an elementary level and to gain knowledge of the fundamental forces of nature by using nuclei as a proving ground.

Experimental and theoretical investigations are leading nuclear scientists to conclude that a new level of understanding of atomic nuclei is achievable. This optimism arises from evidence that: (1) the mesons, protons, and neutrons which are inside nuclei are themselves composed of quarks and gluons and (2) the theory called quantum chromodynamics (QCD) can be developed into a theory which both describes correctly the interaction between quarks and gluons and is also an exact theory of the strong nuclear force. These concepts will be important drivers of basic nuclear research and will determine facility needs in FY 1985 and years beyond.

As is the case with High Energy Physics, the Nuclear Physics program depends upon the operation of large and complicated accelerator facilities which provide a variety of projectile beams required for forefront nuclear research. Seven existing accelerator facilities are operated by the Nuclear Physics program as national facilities whose beam time is made available to all the Nation's scientists on the basis of the scientific merit and technical feasibility of proposed research projects. The national facilities are: the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory (LANL); the Bates Linear Accelerator Center at the Massachusetts Institute of Technology (MIT); the SuperHILAC/Bevalac at Lawrence Berkeley Laboratory (LBL); the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory (ORNL); the 88-inch Cyclotron at LBL; the Tandem/Linac Facility at Argonne National Laboratory (ANL); and the Double MP Tandem Van de Graaff facility at Brookhaven National Laboratory (BNL). These facilities are shown in Figures 7-13.

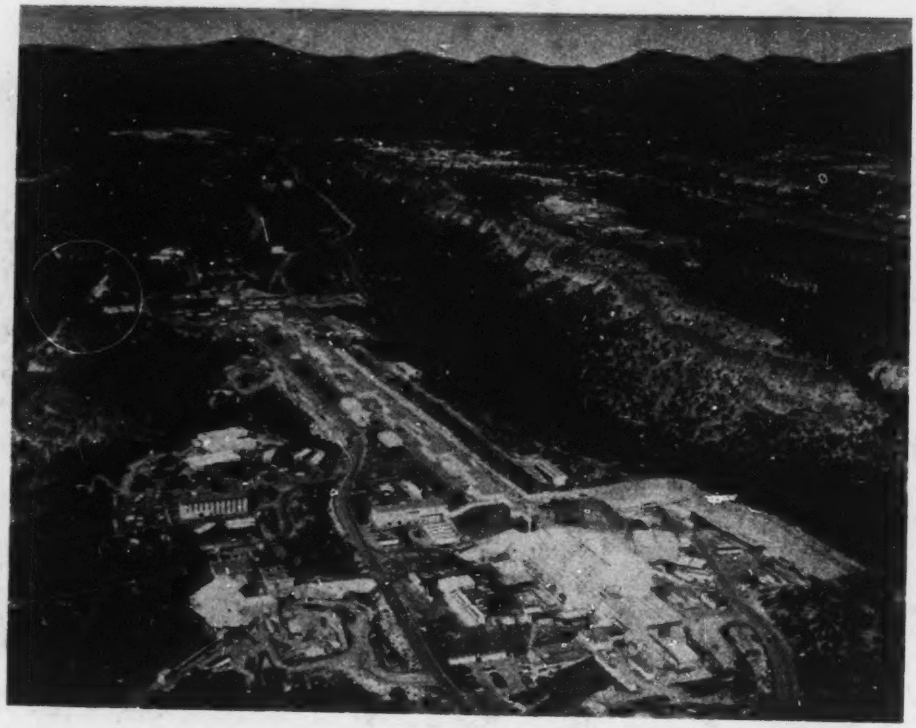


FIGURE 7.—Clinton P. Anderson Meson Physics Facility, Los Alamos National Laboratory

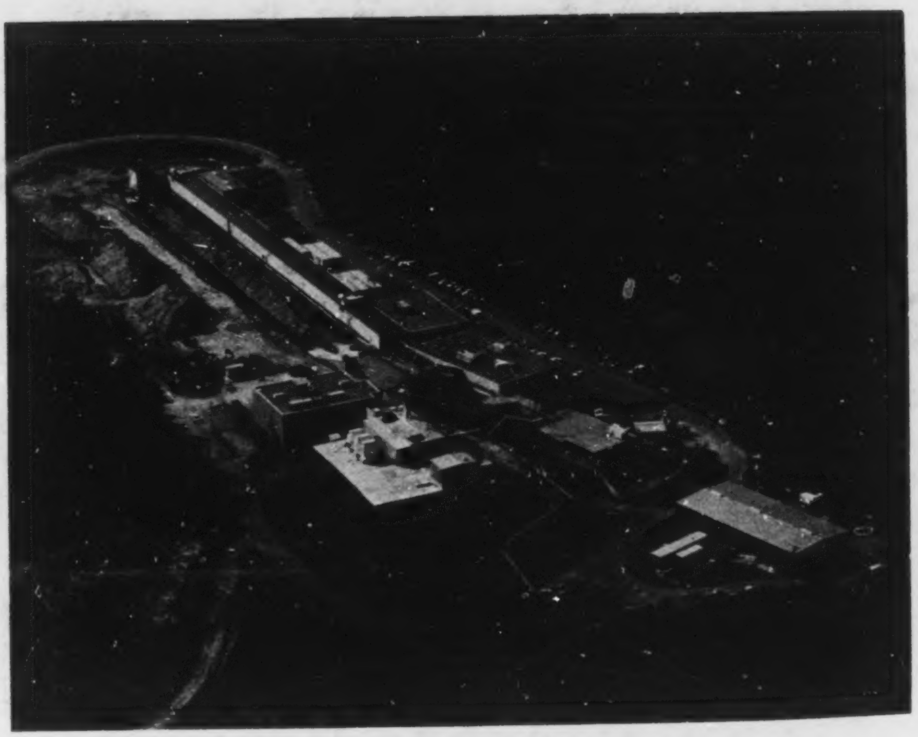


FIGURE 8.—Bates Linear Accelerator Center—Massachusetts Institute of Technology

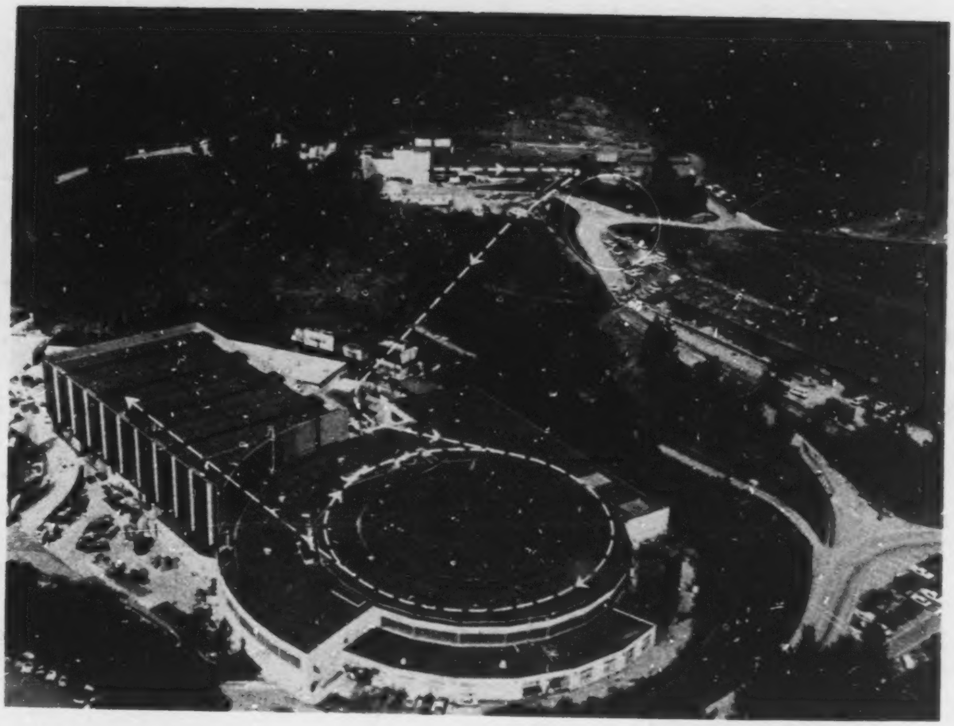


FIGURE 9.—SuperHILAC/Bevelac—Lawrence Berkeley Laboratory

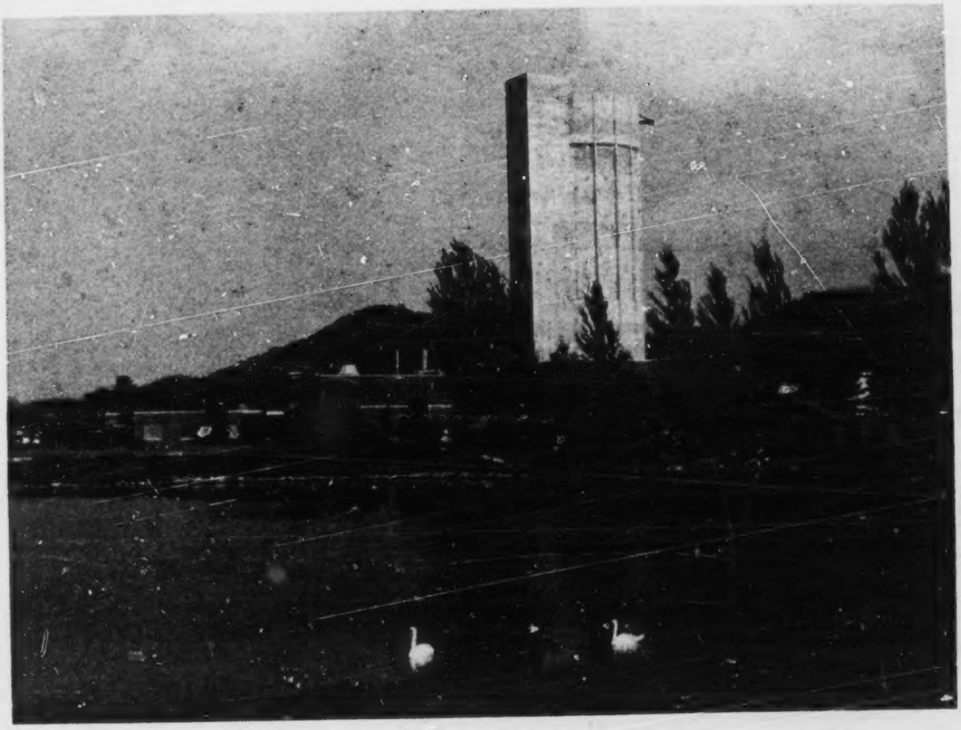


FIGURE 10.—Holifield Heavy Ion Research Facility—Oak Ridge National Laboratory

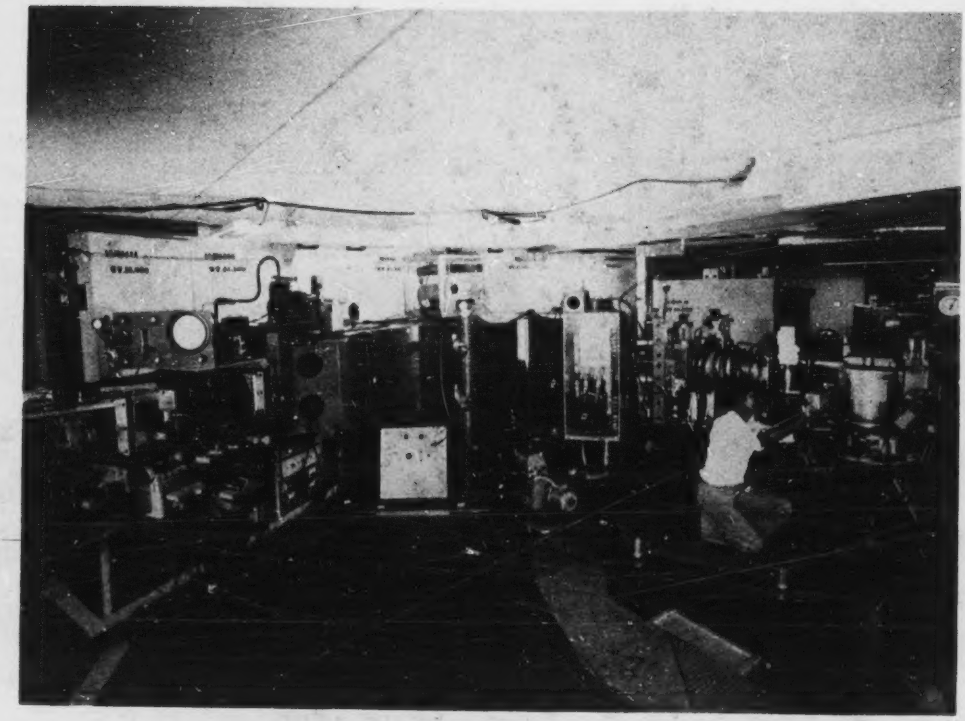


FIGURE 11.—88-Inch Cyclotron—Lawrence Berkeley Laboratory

FIGURE 12.—Tandem/Linac Facility—Argonne National Laboratory

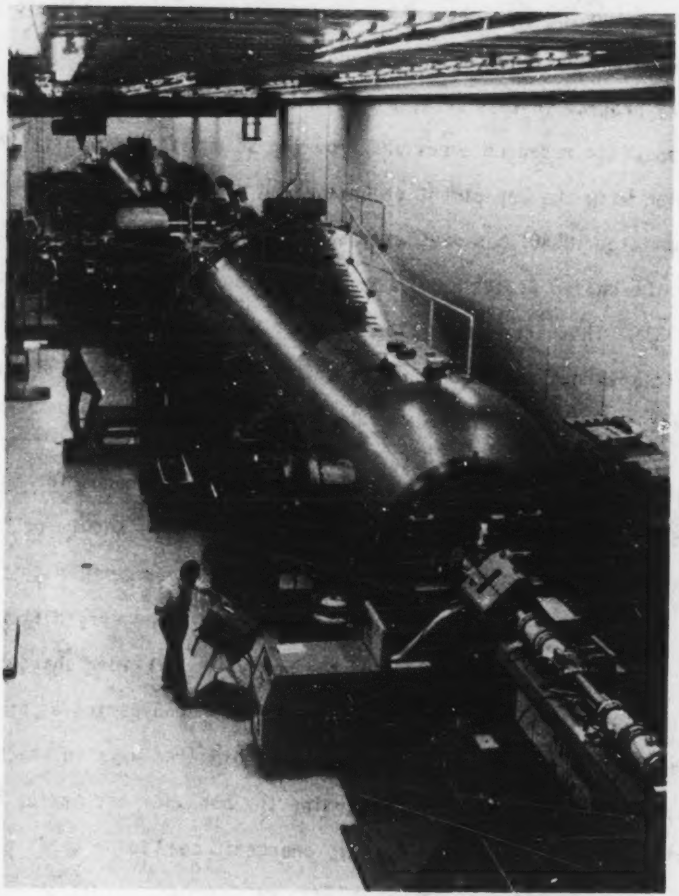


FIGURE 13.—Double MP Tandem Van de Graff Facility—Brookhaven National Laboratory

Long range planning for the needs of nuclear physics research is performed in concert with the National Science Foundation (NSF), which has a smaller, complementary program in this area, and with input from external and internal reviews of specific research areas and from the scientific community itself. In cooperation with the Department of Energy and NSF, the Nuclear Science Advisory Committee (NSAC) has developed a long-range plan for basic nuclear research in the United States -- "A Long Range Plan for Nuclear Science" (December 1983). This long-range plan is based upon a comprehensive review of scientific advances and opportunities which have emerged since development of the previous long-range plan dated December 1979.

The 1983 Long Range Plan reaffirms NSAC's April 1983 recommendation that construction of a 4 GeV, continuous electron beam facility should be initiated as soon as possible, and it identifies a longer term, high priority need for a relativistic heavy ion collider facility. From very different aspects, both the electron facility and the heavy ion collider share the common scientific goals of understanding quantum chromodynamics as an exact theory of the strong nuclear force and understanding the ways in which the quarks inside protons and neutrons determine the behavior and makeup of nuclei. Also, in the interaction of very energetic colliding beams of nuclei, extreme conditions of energy density will occur, conditions which previously existed only in the early instants of creation of the universe. The energy densities will be so great that transitions to new phases of nuclear matter seem likely. If these bright prospects can be realized, a new level of knowledge of atomic nuclei will be achieved. In accord with the Long Range Plan, the FY 1985 construction request provides for initiation of construction of a 4 GeV, continuous electron beam facility at Newport News, Virginia and for a significant advancement in our capability for heavy ion nuclear research at Brookhaven National Laboratory.

FY 1985 Nuclear Physics Budget Request

The FY 1985 request for the total Nuclear Physics program is $183.6 million, which consists of $144.6 million for Operating Expenses, $13.7 million for Capital Equipment and $25.3 million for Construction (Table 4).

Of the Operating Expenses request of $144.6 million, $73.7 million is needed for operation of the existing national and dedicated accelerator facilities to maintain the overall utilization of the national accelerator facilities at 90% of the FY 1984 utilization levels. An additional $1.1 million is required for operation of the new SLAC injector discussed later in my testimony.

The FY 1985 Operating Expense request will allow emphasis to be given to exploitation of new research capabilities provided by successful completion of construction projects in FY 1984 and FY 1985. These include: (1) the Argonne Tandem/Linac Accelerator System (ATLAS) to provide heavy ion beams

Table 4
Nuclear Physics
Budget Authority
($ in millions)

	FY 1984 Estimate	FY 1985 Request
Operating Expenses		
Medium Energy Nuclear Physics	$ 65.0[a]	$ 72.0
Heavy Ion Nuclear Physics	47.0	49.8
Low Energy Nuclear Physics	13.0	13.5
Nuclear Theory	9.0	9.3
	$134.0	$144.6
Capital Equipment	11.3	13.7
Construction	13.7[b]	25.3
Total Nuclear Physics	$159.0	$183.6

[a] Includes $3.0 million which was provided under Defense Programs for LAMPF facility operations.

[b] Does not include $5.0 million proposed reprogramming from the HEP ISABELLE project to the Tandem/AGS Heavy Ion Transfer Line project.

to investigate how colliding nuclei exchange mass, energy, and spin; (2) the Bates Electron Accelerator recirculator project (MIT) which provides electron beams for precision electron-nuclear scattering studies at higher energies than previously available; and (3) a new injector at SLAC to provide high energy, precisely pulsed electron beams to examine the magnetic properties of nuclei and for exploratory experiments into the ways in which quarks influence the makeup and behavior of nuclei. In the FY 1985 Operating Expenses request, $60.5 million is planned for experimental research and $9.3 million for theoretical research.

Of the total FY 1985 Operating Expenses request, 26% is planned as direct support to universities, consisting of off-campus experimental research; operation of Bates and the four dedicated on-campus accelerator facilities; research at on-campus facilities; research and development on the 4 GeV, continuous electron beam facility by the Southeastern Universities Research Association; and theoretical research. Additional university support in an amount almost equal to the direct support is provided through the accelerator centers to support experimental research and operate the accelerators.

As the various Nuclear Physics research programs move into new scientific areas, there is a continuing need to develop new detection instrumentation, upgrade the capabilities of existing instruments, improve the efficiency and sophistication of data acquisition and analysis systems, and improve the performance and beam characteristics at the major Nuclear Physics accelerator facilities. In general, the more complex and precise experiments require the development of entirely new techniques.

The increasing complexity of Nuclear Physics experiments requires larger and more powerful data acquisition and analysis systems. The FY 1985 Capital Equipment request for Nuclear Physics is $13.7 million. This request includes equipment to be used in the first heavy ion experiments at the Alternating Gradient Synchrotron (AGS) at the Brookhaven National Laboratory. At the Lawrence Berkeley Laboratory, the start of fabrication of a major new instrument, the Dilepton Spectrometer, is planned for FY 1985. This instrument will allow researchers to investigate new states of nuclear matter created in very high energy collisions between nuclei. Capital Equipment funds also are needed to exploit the capabilities of the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory and the new Argonne Tandem/Linac Accelerator System (ATLAS) at the Argonne National Laboratory. At the Bates Linear Accelerator Facility at MIT the upgrade of a beam line which feeds three magnetic spectrometers will provide new research capabilities and increased efficiency.

In addition to programmatic equipment needs, the Nuclear Physics program provides for the general purpose equipment requirements for all DOE programs at the Lawrence Berkeley Laboratory.

A total of $25.3 million in Construction funding for Nuclear Physics projects is requested in FY 1985. These projects are listed in Table 5. A major feature of the FY 1985 Nuclear Physics program is the initiation of construction of the Continuous Electron Beam Accelerator Facility project

Table 5
Nuclear Physics
Budget Authority
($ in millions)

Construction	Prior Years	FY 1985 Request	TEC	Completion Date
Univ. Accelerator Upgrade (84-ER-110)	$8.0	$ 11.0	$ 19.0	FY 1987
Tandem/AGS Heavy Ion Transfer line (84-R-123)	$5.0a/	5.3	10.3	FY 1986
Accelerator Improvements Projects (85-R-200)	N/A	3.5	N/A	FY 1987
General Plant Projects (85-R-201)	N/A	3.5	N/A	FY 1987
Continuous Electron Beam Accelerator Facility (85-R-203)	0	2.0	b/	b/
Total Construction		$25.3		

a/ Proposed reprogramming from ISABELLE construction project (78-10-6)

b/ The total estimated cost and exact construction dates are under review. The FY 1985 request provides for architect-engineering work, detailed design, and preliminary site work.

(CEBAF) at Newport News, Virginia. This will be a major facility employing an electron linear accelerator complex capable of delivering intense, continuous electron beams in the energy range from 500 million to 4 billion electron volts. The intensity (number of particles per second) of the beam in combination with multi-GeV energy and uniquely high duty factor (continuous rather than pulsed beam) will make this facility unmatched in the world. The CEBAF will have the capability of investigating a crucial class of problems facing nuclear physics today, namely, understanding the relationship between the traditional and emerging descriptions of nuclear dynamics. The aim is to synthesize the traditional picture and the emerging view of an underlying structure of quarks and gluons into a unified description.

In FY 1985, $2.0 million in Construction funds will be used for architectual and engineering services, for minor site work, and for design beyond the conceptual level in order to establish a reliable cost estimate for the CEBAF project.

The Nuclear Physics Construction budget also requests funds for the ongoing construction of the University Accelerator Upgrade Project at the University of Washington and Yale University ($11.0 million) and for the Tandem/AGS Heavy Ion Transfer Line project at Brookhaven National Laboratory ($5.3 million). The FY 1985 request completes funding for these construction projects. The University Accelerator Upgrade Project at the University of Washington and Yale University will maintain the forefront nuclear research capabilities of two of America's leading universities.

The objective of the Brookhaven project is to transport beams of nuclei as massive as sulfur (32 atomic mass units) from the existing Double MP Tandem Facility to the Alternating Gradient Synchrotron (AGS) for acceleration to energies of 15 billion electron volts per atomic mass unit. This project will provide an exciting new capability for research in heavy ion collisions in a new higher energy region, and is an excellent complement to Bevalac's existing lower energy (1 to 2 billion electron volts per atomic mass unit) but much higher mass (up to uranium at 238 atomic mass units) beams. Research at the Bevalac shows that concentrations of mass and energy do occur in energetic collisions of massive nuclei. Tandem/AGS Heavy Ion Transfer Line beams will extend our capabilities into regions in which the quarks inside nuclei will be violently forced together, possibly producing a transition of nuclear matter into new forms.

The request also provides $3.5 million for Accelerator Improvement Projects (AIP) at Nuclear Physics facilities taking into account the needs of the recently completed facilities now being operated, and $3.5 million for an improved level of General Plant Projects (GPP) with particular emphasis on the needs at LBL, where this program provides funding for the general purpose needs of all DOE programs.

GENERAL SCIENCE PROGRAM DIRECTION

The FY 1985 budget request for General Science Program Direction is $2.2 million. These funds are required to provide for the salaries, benefits, travel and other expenses associated with 35 full-time equivalents in the Office of the Associate Director for High Energy and Nuclear Physics and associated support staff required to administer these programs.

Mr. Chairman, that concludes my testimony. I would be happy to answer your questions.

Mr. **Fuqua**. Thank you very much, Dr. Trivelpiece. I failed to get permission from Congressman Winn to insert his statement in the record immediately following my statement, and without objection it will be included in the record.

You mentioned, Dr. Trivelpiece, some moneys for capital improvement. About how much money is included for capital improvement in the overall budget that is under your jurisdiction, the one we are discussing today?

Dr. **Trivelpiece**. For high energy physics, it is $65 million.

Mr. **Fuqua**. Does that include planning funds, such as some of the preliminary work for the new large——

Dr. **Trivelpiece**. For the SSC?

Mr. **Fuqua**. Yes.

Dr. **Trivelpiece**. No. That is strictly capital equipment money that is used for detectors, the complicated pieces of equipment that integrate many pieces of apparatus that are used to detect particles and their products and their collisions.

Mr. **Fuqua**. What about capital improvements, such as buildings?

Dr. **Trivelpiece**. Construction is $114 million.

Mr. **Fuqua**. So the $65 million would be for equipment improvements, and the $114 million for buildings and so on?

Dr. **Trivelpiece**. Yes.

Mr. **Fuqua**. The other question that I had was, you were talking about the interaction with universities, the national laboratories, and industry. I want to applaud you for that because I think it is a very worthwhile program.

I was interested in an article that appeared in The Washington Post this morning, quoting Dr. Wilson from Cornell, whose credentials I think are well known to all of us. He was talking about the interaction of supercomputers for the country but also while not directly related, does that apply very strongly to some of the high-energy physics and basic energy science programs?

Dr. **Trivelpiece**. Yes, it certainly does. I have testified previously on this subject. You know I am a strong enthusiast and advocate of trying to increase the access to scientists at universities and laboratories to supercomputers as well as trying to see the U.S. Government take some lead in improving or creating the conditions that will accelerate the creation of the next generation of supercomputers. So I strongly support what Ken Wilson said yesterday in that press conference.

Mr. **Fuqua**. I assume that the funds are included. You did not mention it in your statement directly. I glanced at your prepared statement, and I did not see it, but it could be there. What about the materials laboratory at Berkeley? Are funds included for that?

Dr. **Trivelpiece**. I get to testify again tomorrow on the basic energy sciences program, and that will be one of the subjects. I would be happy to discuss it today.

Mr. **Fuqua**. We have a full house today, so we will defer until tomorrow then.

Mr. Winn?

Mr. **Winn**. Thank you, Mr. Chairman. I get to ask the questions today.

Dr. Trivelpiece, I just wondered in a general sense why have the operating costs for the high energy physics facility increased on the average by about 11.6 percent? Maybe a good second question, and then you can throw them all into one, is: Has the department projected the cost of operating these facilities in the future?

Dr. **Trivelpiece**. I think a better way to ask the question—not to correct you—is to point out that the operating level of these facilities in the past was probably unfortunately lower than it should have been. The pressures on the budget in the past resulted in these expensive facilities being set up and put in place and people brought there and then not allowed to operate at a level that is consistent with that investment.

We have tried to reverse that trend, and indeed have increased the amount of funds devoted to operation of the facilities. We think that is important. It is a little bit hard to say what is the optimum level, and it is a little hard even to define what constitutes the operating level itself, but it is clear that it has been too low. It is getting better, it could be better. There does reach a point at which the setup time and the construction and other things that go on around these facilities make it impossible to operate them at 100 percent, but it is estimated rougly now that we are in the 55-percent range. It should be better.

Yes, we have increased that. Yes, I think it is the right thing to do. I think it has been too low in the past.

Mr. **Winn**. Are you saying you are just really sort of catching up? Would that be a good way of saying it?

Dr. **Trivelpiece**. We are getting up to a level that is consistent with the investment in the facilities. I think catching up probably is a good term.

Mr. **Winn**. Well, then, the next question would be, Why are the nuclear physics facilities to be operated at only 90 percent of the 1984 levels? Would that be the same reason?

Dr. **Trivelpiece**. In my closing remarks, I said it is a question of balance, of trying within the budget constraints with which we have to deal to see to it that new facilities are made available for the areas in which research needs to be done and trade that off against the operation. The starting of the new facility at Southeastern University Research Association, the CEBAF project, is going to put some pressure on the budget. In order to start that, something had to yield.

Mr. **Winn**. Mr. Chairman, I have to leave, but I would like to followup on that line of questioning by submitting some questions to you. Possibly you could help clarify the questions that arise in the minds of the members of the committee. Thank you, Mr. Chairman.

Mr. **Fuqua**. Thank you, Mr. Winn.

Also Congressman Boucher asked permission to extend his remarks following those of Mr. Winn. Without objection, Mr. Boucher's remarks will be included.

[The prepared statement of Mr. Boucher follows:]

Because of a mark-up in the House Education and Labor Committee on H.R. 4164, the vocational Education Amendments, I will be unable to attend today's hearing of the Energy Development and Applications Subcommittee, and I regret that I will therefore be unable to listen to the testimony of the nuclear physics witnesses, including Dr. Harry Holmgren and Dr. James McCarthy of the Southeastern Universities Research Association.

I am a strong supporter of the SURA project, and I will be working with my colleagues on the subcommittee to assure full funding of SURA's budget request for this year. I believe that the SURA project is critical to our national nuclear physics research effort, and I look forward to assisting with this project in the coming months.

Mr. FUQUA. Mr. Durbin?

Mr. DURBIN. Thank you, Mr. Chairman. I would just like to echo the comments made by Congressman Winn in his concern over the level of funding, that 90 percent utilization level. It strikes me as perhaps a waste of the facility that we have funded and created, and I am wondering if we are embarking upon new ideas and new projects at the expense of proven ideas which could be perhaps developed more fully this year. I assume from your answer that you considered that and reached the conclusion that it is better to underutilize a facility and move out in new directions.

I will not try to second-guess you on it, but I will add that I share the concern of Congressman Winn over that.

Dr. TRIVELPIECE. I share the concern also. It is a question of balance. Many elements, decisions, and concerns go into making up a budget, not the least of which is the pressure on the overall budget. We believe we have achieved, within the constraints within which we have to live, a fair balance, taking into account the needs of the program and the like.

Mr. FUQUA. I appreciate your coming this morning.

Mr. Sensenbrenner.

Mr. SENSENBRENNER. Mr. Chairman, I ask unanimous consent that an opening statement of mine be placed in the record, and I have one further comment, which is not in the nature of a question. I think that the budget request of the administration this year, for once, is a realistic budget request. There are some substantial increases that are being proposed in practically all of the areas under discussion at this hearing today. I am hopeful that now that the administration has become realistic so will the majority on this committee be realistic and we abandon our previous position of having some substantial add-ons to the DOE budget before it is reported to the full committee and, ultimately, to the floor. It seems to me that one good turn deserves another, and Dr. Trivelpiece, you are commended for casting the first good stone.

[The opening statement of Mr. Sensenbrenner follows:]

OPENING STATEMENT OF THE
HONORABLE F. JAMES SENSENBRENNER, JR., (R-WIS)
EDA SUBCOMMITTEE HEARING ON
DOE HIGH ENERGY PHYSICS
AND
NUCLEAR PHYSICS PROGRAMS FOR FY85

FEBRUARY 22, 1984

THANK YOU, MR. CHAIRMAN, FOR THIS OPPORTUNITY TO EXTEND A WELCOME TO DR. TRIVELPIECE, DIRECTOR OF THE OFFICE OF ENERGY RESEARCH IN THE DEPARTMENT OF ENERGY, AND TO OUR DISTINGUISHED PANELISTS.

I LOOK FORWARD TO DR. TRIVELPIECE'S TESTIMONY THIS MORNING ON THE HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS PROGRAMS CONDUCTED BY HIS OFFICE.

THE ADMINISTRATION HAS PROPOSED SIGNIFICANT INCREASES IN

THESE PROGRAMS FOR FISCAL YEAR 1985. THE HIGH ENERGY PHYSICS BUDGET IS INCREASED BY 14.5 PERCENT FROM FY84 AND THE NUCLEAR PHYSICS BUDGET IS INCREASED BY 13.4 PERCENT. FURTHER, WHEN COMPARED AGAINST FY83, THE PROGRAMS HAVE INCREASED BY OVER 23 PERCENT AND 25 PERCENT RESPECTIVELY.

WHILE I SUPPORT THE STRENGTHENING OF THESE FUNDAMENTAL RESEARCH PROGRAMS, I BELIEVE WE MUST INSURE THESE INCREASES ARE IN FURTHERANCE OF A COHERENT RESEARCH POLICY THAT IS SOUND BOTH SCIENTIFICALLY AND FISCALLY. THUS, I LOOK FORWARD TO OUR PANELISTS' THOUGHTS ON THESE PROGRAMS AND TO WORKING WITH YOU, MR. CHAIRMAN, AND MY COLLEAGUES ON THIS SUBCOMMITTEE, IN DEVELOPING A FOREFRONT PHYSICS RESEARCH PROGRAM FOR THIS COUNTRY.

Mr. **Fuqua**. Mr. Carney?

Mr. **Carney**. Thank you, Mr. Chairman. I would simply like to welcome Dr. Trivelpiece here today. It is always a delight to have his testimony and his knowledge for when we formulate budget issues.

Dr. Trivelpiece, my first question is, what is the purpose of the $20 million requested in fiscal year 1985 for the SSC?

Dr. **Trivelpiece**. It is a continuation of the collection of activities that we have begun this year as a result of the reprogramming requested and testified upon earlier before this committee. It includes some efforts at identifying cost-reducing approaches to superconducting magnets, to reference design activities, to the early identification of site criteria issues, and related things like that. I would be glad to supply a breakdown of that for the record.

[The material referred to follows:]

SSC PLANS FOR FY 1985 FUNDS

The present plan for allocation of the $20 million requested for SSC R&D in FY 1985 would be as follows:

Superconducting Magnet R&D (R&D and cost-reduction studies on four magnet concepts; fabrication and testing of small models)	$15.5
Design Studies (Accelerator and systems design; trade-off and optimization studies)	2.0
R&D on other technical systems (Primary effort on cryogenics)	1.0
Integration Group (Responsible for integration and coordination of national SSC effort, conceptual design report, cost estimate, and site criteria document)	1.5
	$20.0

Mr. Carney. If my memory serves me correctly, we signed off, I guess would be the correct term from the Hill standpoint, on a reprogramming of fiscal year 1984 funds for $19.5 million. Would that be for precisely the same thing?

Dr. Trivelpiece. To a first approximation, it is a continuation of that collection of activities. There are some minor changes that have been made in the emphasis, but that is essentially correct.

Mr. Carney. I am hoping not to get my colleague from Wisconsin upset. My next question would be, in light of the fact of the July 1983 HEPAP recommendation that the immediate initiation of a multi-Tev high-luminosity proton collider project, with a goal of physics experiments at the facility at the earliest possible date—and we were talking then perhaps early 1990; 1994 was mentioned; construction starts of 1988 were mentioned—we are talking, I think, a 20-Tev by 20-Tev proton-proton collider.

My question is, are we not being somewhat stingy with the amount of money to be allocated for the superconducting super collider if we are to maintain that type of timeframe? Will we slip now several years?

Dr. Trivelpiece. No, I do not believe so. The first thing is that a careful determination of what it is that will be built needs to be made. That requires some reference design effort. That effort is in progress. Secretary Hodel has asked us to carry out this reference design work this year on the reprogrammed funds, and then launch into next year's activities based on some recommendations that we will be obliged to make to him later in our own budget cycle this year.

Mr. Carney. Will that decision be made or is it not tentatively expected to be made in August of 1984, the calendar year?

Dr. Trivelpiece. I am not sure when it will be made. We will present to Secretary Hodel as soon as we can the necessary information. I hope that it is no later than August because in part it will be tied up with our own internal budget planning for 1986.

Mr. Carney. The schedule of key activities and milestones to SSC says that in June, DOE reviews the R&D plan and management plan for phase I, which has not started. We are in phase zero? I do not mean that sarcastically. What are we calling it? It is not phase I.

Dr. Trivelpiece. It is a continuum of activities, and for convenience they have been broken up into phase zero and phase I. I think Secretary Hodel prefers to refer to what we are currently doing as phase zero. Namely, we should be looking carefully at what constitutes the elements of the program and what are the cost-reducing design activities and the like. That phase will end sometime this year, prior to the beginning of the next fiscal year. Precisely when depends on when we get our work done and our information presented to him.

Mr. Carney. Our targeting time, a DOE decision on whether to proceed with Phase I is targeted for August; is that not correct?

Dr. Trivelpiece. I think you are drawing it too starkly if you say a decision on whether or not to proceed. We are proceeding now on the presumption that this activity will go forward. We do have various checkpoints and milestones within the department, procedures in which we are required to report to the Secretary from time to time what we are doing. To that extent, you could say it is a decision. But I think as a practical matter we are on a process which is predicated for completion.

Mr Fuqua. When we go around we can come back to you.

Mr. Carney. Thank you, Mr. Chairman.

Mr. Fuqua. Mr. Bateman?

Mr. Bateman. Thank you, Mr. Chairman. Perhaps I can finish quickly and yield some time.

Dr. Trivelpiece, I join in welcoming you to the committee. I note in your testimony the references to the continuous electron beam accelerator facility, the 4 GeV facility. In your testimony, it is characterized as something that should be initiated as soon as possible and has been identified as having a long-term high priority, as well as something that we need to press on with for immediate research. Have you found that the Department of Energy's recommendation of this facility has met with general support within the nuclear physics community?

Dr. Trivelpiece. Yes.

Mr. Bateman. Do you feel that if the recommendations of the Department and the administration's budget are adopted that it represents as much progress as can be made toward its completion in fiscal year 1985?

Dr. Trivelpiece. I think it is a realistic level of funding for what we believe needs to be done, given the fact that it is a new facility starting without infrastructure or pre-existing laboratory. It is a very realistic budget level.

Mr. Bateman. I would only say as a volunteered reaction that it is a remarkably talented group of people, and that infrastructure could be put together very rapidly and in fact is being put together very rapidly.

Dr. Trivelpiece. I have noticed.

Mr. Bateman. I am sure they have made you very aware of that. Mr. Chairman, those are all the questions I have at this time. Unfortunately, I have to leave the committee to go to an exercise commemorating Washington's birthday but will return as quickly as possible. Should I not get back, there are some other witnesses to whom I might want to present some questions in writing, if I could reserve that right, Mr. Chairman.

Mr. Fuqua. Sure.

Mr.Mineta?

Mr. Mineta. Thank you very much, Mr. Chairman. I welcome Dr. Trivelpiece.

What is the total cost of the SSC estimated at? Do we have any ballpark figure at all?

Dr. Trivelpiece. I hesitate to get into making estimates at that point, because I think that has contributed to some of the problem. Estimates have ranged from a couple of billion to $8 billion, and I think that is a problem. I would prefer that the department carry out a systematic reference design effort, and from that reference design effort make some preliminary cost estimates and that those preliminary cost estimates be made available.

Later on, Dr. Tigner will be testifying, and you may certainly ask him what progress they have made on that. But from an official departmental point of view, I would prefer not to make estimates at this stage.

Mr. **Mineta**. Let me pursue it another way. Given the costs that might be involved in this thing, are we looking at the possibility of getting cooperation from other countries in order to offset some of these costs and share the knowledge that comes out of this program?

Dr. **Trivelpiece**. As I said in some of my opening remarks, high-energy physics is characterized by a remarkable degree of international cooperation and collaboration. But as the facilities that are to be needed begin to exceed costs that are in the billion-dollar category, perhaps a new pattern needs to be established with regard to how we do go about international collaboration. The Versailles, Williamsburg, and London summit process has provided us a vehicle by which to explore those things, and earlier this year, I met with some of my counterparts from other countries to discuss how we might go about doing that and making a recommendation to the heads of state for their consideration at the London summit conference.

I think a new form of collaboration really needs to be examined. Dr. Richter has served as a member of the committee that we appointed for that purpose. You might wish to ask him about some progress they have made on their committee meetings which they have just completed.

Mr. **Mineta**. Our very distinguished Chair, Dr. Fuqua, took us to Switzerland last year. Is there any possibility or any approach being made at CERN about having a scaled-down SSC, given their LEP facility?

Dr. **Trivelpiece**. The LEP facility, at least at the moment, is for electron-positron collisions and not for proton-proton or proton-anti-proton, although the Europeans do have plans for eventually putting into that tunnel magnets that would make it possible to have a proton collider. The circumference and the diameter of that tunnel are such that the highest energy with magnet technologies that we are now familiar with would probably be limited to something in the order of 10 TeV on 10 TeV. That may or may not be at an energy level which is necessary in order to produce the results that have been identified by members of the High Energy Physics Advisory Panel as being appropriate for the next facility.

But certainly, there is a degree of cooperation with them. We are aware of what they are doing. Some of the other people who will testify later today are also very familiar with these activities and I am sure will be glad to add information.

Mr. **Mineta**. How high in energy would you have to get?

Dr. **Trivelpiece**. Well, 20 on 20 is the current defined goal of the superconducting super collider project for the United States.

Mr. **Mineta**. But the energy costs are geometric, in terms of the increase, rather than arithmetic, in terms of the costs involved in getting from one level to another?

Dr. **Trivelpiece**. I am not sure what the scaling law is on that. Dr. Leiss might be able to help.

Mr. **Mineta**. Is it proportional, in terms of its relationship?

Mr. **Leiss**. I think the quadratic dependence on energy is correct for circular electron-positron colliding facilities, but for a given style of magnet, for a proton-proton collider, it is proportional to the energy.

Mr. MINETA. Mr. Chairman, I have some other questions, but we will have an opportunity for a second round.

Mr FUQUA. Thank you. Mrs. Schneider?

Mrs. SCHNEIDER. I am hopeful that since Mr. Mineta has already asked my questions, I may now ask some of his to followup on that same topic.

I was wondering if you could elaborate a little bit more on the application of the SSC?

Dr. TRIVELPIECE. The application?

Mrs. SCHNEIDER. Yes.

Dr. TRIVELPIECE. It is a physics facility that will cause protons to collide with protons at a high enough energy to produce new states of matter that are of interest to be explored by the scientists who are involved in this activity.

Mrs. SCHNEIDER. Ultimately leading to what practical use?

Dr. TRIVELPIECE. A better understanding of nature. The purpose of this program at any given instant in time is to understand the fundamental constituents of matter and the forces that influence their behavior. It is never started with a particular application in mind. It is not applied physics; it is basic physics. For the most part it is curiosity-driven. You only have to look back over a 10-, 15-, or 20-year time scale, however, to appreciate the number of things that have come about. The entire nuclear industry owes its existence to certain watershed events in this field, as does the entire nuclear medicine business in the United States, such as radiation processing and so on.

There have been many applications that have come out. If you had gone back and asked the same question then that you are asking now, the answer would be the same. You would have to look back over some time base in order to determine what has emerged as benefits.

Mrs. SCHNEIDER. Are you of the opinion that the impact of this $3 billion to $8 billion line item would be positive on the overall DOE budget?

Dr. TRIVELPIECE. Postive what? Influence?

Mrs. SCHNEIDER. Yes; that is a substantial amount of money. Granted, Mr. Mineta had recommended the pursuit of cost-sharing on the part of other nations. What if this committee were to say that we were less inclined to support the funding of this project unless you could guarantee a cost-sharing program with other nations?

Dr. TRIVELPIECE. I think it is important, first, to determine what the real costs are, and that is what the reference design activity is about. I think next it is important to explore new approaches to international collaboration. However, I think it would be a mistake, given the needs of the United States for talent and the role which activities like this play in national excellence in talent, to put ourselves in a position in which we insisted that in order to proceed there be some contribution by one or more other countries.

Mrs. SCHNEIDER. Of course, the effort would be a cost-saving one, when we are looking at a $183 billion deficit. Our responsibility is to be as cost-efficient as possible. This is a very large-ticket item that will require, I believe, an enormous amount of justification.

Dr. TRIVELPIECE. I hope that the activities that have taken place, in terms of turning our economy around, are such that by the time the bill comes due for this, we can afford it rather simply, and it would not be an activity that would be at such variance with the economic needs of the country.

Mrs. SCHNEIDER. Are there any thoughts as to where this particular facility would be located?

Dr. TRIVELPIECE. There are a lot of thoughts about where it might be located. Hardly a week goes by in which I do not get an offer to have it in some particular location in the United States

Mrs. SCHNEIDER. But you have not narrowed it down?

Dr. TRIVELPIECE. No; I think it is actually inappropriate, until we know technically what we are talking about and what the needs are and come to a final conclusion as to what the site criteria should be. Then at that time a competitive selection to determine the site should be done. First, the technical what, and then subsequently, the location, where.

Mrs. SCHNEIDER. Could you please bring me up to speed as to what is being done in your preliminary or very basic nuclear waste research activities, the disposal of nuclear waste?

Dr. TRIVELPIECE. That is not an activity for which I have any responsibilities.

Mrs. SCHNEIDER. None whatsoever? You are not involved in some of the basic research?

Mr. TRIVELPIECE. There is some basic research in the basic energy sciences program, which I could be prepared to talk about tomorrow. We do some studies, but they are of a basic nature. We are not involved directly.

Mrs. SCHNEIDER. I am aware that they are basic, and if you could prepare it tomorrow, I would be interested in some response on that. Thank you.

Mr. FUQUA. Mr. Simon?

Mr. SIMON. Thank you, Mr. Chairman.

In response to my colleague from Rhode Island's reference to the site, I have looked this whole thing over very carefully, very objectively, and I have come to the conclusion that Illinois is a natural site for this proposal.

I am curious. In response to my colleague from California, Mr. Mineta, you talked about a new form of international cooperation. In response to Mrs. Schneider, you talked about new approaches to international cooperation. I think it should be encourgaged both for cost reasons and, frankly, also to build bridges of understanding with other countries. What are we talking about in new forms, new approaches?

Dr. TRIVELPIECE. I understand. The procedure in international collaboration and cooperation normally involves one country building a facility. They build a facility entirely with, within-country funds. Then other countries participate in the science by bringing what is called personal property. This can include expensive detectors, equipment, computers, and whatever. The premise always is that you can take that property home with you if you happen to get in disagreement with the host country. In practice, the equipment tends to stay there forever, and eventually it becomes cannibalized and gradually incorporated into part of the basic facility.

What has been hard to do in the past, and for which perhaps some new rules need to be explored or some new approaches need to be explored, is to have several countries simultaneously lay on the table resources and agree in one place to build a facility and have the civil construction be shared by more than one country. That tends not to have been the way it has been done in the past. It has been only the personal property.

That could be a very expensive proposition in a facility such as the superconducting supercollider, because the detectors themselves which could be provided by another country or we could provide to another country are themselves becoming devices which are in excess of $100 million cost. So it may be possible to get substantial cooperation and still stay within the personal property problem, and it may be that new arrangements could be worked out whereby a transfer of funds and the civil construction could take place under those terms. Building bridges is very hard, real bridges, social bridges, is a good idea.

Mr. SIMON. Thank you, Mr. Chairman.

Mr. FUQUA. Thank you. Mr. Carney, did you have any further questions?

Mr. CARNEY. Yes, Mr. Chairman. With your indulgence, I have a few.

If I may, Dr. Trivelpiece, I want to pursue the question that my colleague from Rhode Island raised just a little further. You talked about what is out there, and in order to do that, you have to look 20 years before and find out what those discoveries created for a track record. How long has it been since we have known the basic particle of matter, the atom?

Dr. TRIVELPIECE. This last year, 1982, saw the 50th anniversary from 1932 for the discovery of the positron and the neutron and certainly a recognition at that level was in the thirties. The Hahn-Strassman experiments took place in the late thirties, in terms of nuclear fission.

Mr. CARNEY. We are talking the advances we have made in 50 years. If we had asked the same question 50 years ago, what would be out there, I am sure a person in your position—certainly not with DOE but with whoever was here, shepherding a program of that nature—would have the same problem answering it. We do not know what is out there, but we expect what is out there to be very exciting, and we expect that what can happen, as far as spinoffs in applied science could be unlimited. Now we have nuclear medicine. We have technologies for developing diagnoses, through the discoveries that were made in a time frame of 50 years.

I think the challenge is to find out what is out there. What is out there is the challenge. After finding out those questions, we then decide how we apply that for the betterment of man. It is a difficult thing because it is not tangible. In terms of a $180 billion budget deficit, it is going to take people with vision to realize the importance of these types of programs. I just would like to put my 2 cents in the record on that particular issue.

Getting back to some of the questions, here is where I do have concern. If we stretch out these programs, we know what the track record brings: Additional costs, overruns, lack of support eventually, and a tarnished record in areas, whether it be high energy physics or whether it be building a canal somewhere. In our country, it does not matter. In order to continue to maintain support, we have to know where we are going and have good ideas on what it is going to cost us as far as resources in both time and money. That is what I am concerned with today.

Reading the reports, the HEPAP report, and reading testimony of yourself last October, we are looking at a much more energetic time frame. We said in HEPAP, in early 1983, that we would be looking at perhaps $150 million in research and development over a period of 4 years, which roughly would break down to about $38 million. My concern is that we are not trying to fund those levels right now. My concern is that just today you said you feel strongly the program will go on, yet we will not know that answer until August or September or whatever.

If we do go on, will there be enough money in fiscal year 1985 to go on aggressively, to maintain our scientific community intact, so we do not continue to have an erosion of our top scientists to countries other than the United States? I would even yield to my colleague from Illinois saying perhaps it should be in Illinois. It certainly cannot fit on Long Island; I do not want it. But wherever they want it, we will put it, but I think we need it. That is my feeling. I question whether we have enough money.

Dr. TRIVELPIECE. That is a very interesting leading question. You will recall, of course, that I am a representative of the administration and the President has, through his budget submitted to the Congress, identified what is in his opinion the correct level for these activities. Of course, I support that. I think we can make adequate progress with the funds that have been requested. Certainly, the scientists who are interested in this field would like to see it move much faster than we are probably prepared to propose at this point.

Mr. CARNEY. My colleague said, would it be all right in Rhode Island. I hate to inform her, it would not fit in Rhode Island, in all due respect.

Dr. TRIVELPIECE. One of the suggestions for a site that was made earlier on was to arrange this in such a way that, in view of the fact that these beams can be steered with magnets rather effectively, is to cause it to pass through the physics department of about 20 universities located on the eastern seaboard. In that way, there would be a better support base.

Mr. CARNEY. High energy physics is starting to operate like the Pentagon. Put it in 218 districts, and you can get any program. I really share those concerns, and I am sure in the budget process, Mr. Chairman, we as a committee are going to have to address that. I am frightened that we are going to say yes, recognizing the importance of it in August, in September or even in October, and then not have the money aggressively to go forward, pushing it off another year. As you know, delays cost money, and delays are going to cost us support in this committee. That is my concern.

Dr. TRIVELPIECE. Could I add something? I think there is a difference to be drawn between costs during a planning phase and delays during a construction phase. Once a construction schedule has been laid out, and a cost envelope has been determined, and the preliminary pieces of material have been acquired, then a delay results in a clear increase in costs. A level of funding such as we are proposing during a planning phase does not necessarily result in a direct increase in cost. What in my view is bad to do is to break the construction envelope.

Mr. **Carney**. Mr. Chairman, I heard the bell ring.

Mr. **Fuqua**. I might point out, we have six other witnesses, too, this morning.

Mr. **Carney**. Could I throw one hand grenade at Dr. Trivelpiece?

Mr. **FuQua**. A small one.

Dr. **Carney**. The question I have is, If not SSC, what in high energy physics?

Mr. **Trivelpiece**. I do not know. Could I think about that and provide an answer for the record, if that were appropriate?

[The material referred to follows:]

IF NOT SSC, WHAT?

The U.S. high energy physics community has concluded that future progress in understanding the fundamental laws and particles of nature requires that the next major facility to be constructed should have properties sufficient to allow detailed studies in the mass region of 1-2 TeV. The Superconducting Super Collider (SSC) is the machine proposed for these studies. The SSC could be available for research in the mid-1990's. With the completion in FY 1986 of Tevatron I and the Stanford Linear Collider (SLC), the high energy physics program, at this time, has no plans other than the SSC for future new facility construction.

A linear electron-positron collider, which could in principle bring us into the same energy domain, or above, is well off in the future. The basic technical feasibility of such a device will not be known until operation of the Stanford Linear Collider in 1987, and even after that, a substantial R&D effort will be required to make possible a facility of reasonable cost and electric power consumption.

A facility with substantially reduced energy (such as the previously proposed Colliding Beam Accelerator or the Fermilab Dedicated Collider) would not be a competitive world class facility in the mid-1990's.

Developments in other countries include the UNK facility in the USSR (3 TeV proton fixed-target and 3 TeV by 400 GeV proton-proton colliding beam facility under construction, and later a 3 TeV x 3 TeV proton-proton collider) and, being considered in Western Europe, a 5-9 TeV x 5-9 TeV hadron-hadron collider in the Large Electron Positron tunnel.

If the decision is made to not construct the SSC, the U.S. high energy physics community will be able to conduct research in the mass range of interest only by collaborative research on the facilities in the USSR or Western Europe, if they become available.

Mr. Carney. Yes; I would appreciate that very much. Knowing that we have such distinguished panelists waiting, I have a series of questions. Believe it or not, they are easy questions, but rather than hold you and other panelists, I will submit them in writing.

Dr. Trivelpiece. I think that is a fun question you should ask some of them when you have a chance.

Mr. Carney. I am going to take that opportunity. I appreciate the indulgence that the Chair has given me today.

Mr. Fuqua. Thank you, Mr. Carney, and Dr. Trivelpiece. We thank you both for being here, and we will see you tomorrow.

Will Dr. Tigner, Dr. Lederman, and Dr. Richter please come forward.

Dr. Tigner, we are happy to have you here as the director of operations at the Wilson Synchotron Laboratory at Cornell University. Dr. Lederman is the director of the Fermi National Accelerator Laboratory in Illinois. Dr. Richter is the technical director and the incoming director of the Stanford Linear Accelerator Center in California.

Dr. Tigner, we are happy to have you with us today.

STATEMENT OF DR. MAURY TIGNER, DIRECTOR OF OPERATIONS, WILSON SYNCHOTRON LABORATORY, CORNELL UNIVERSITY, ITHACA, N.Y.

Dr. Tigner. Thank you, Mr. Chairman and members of the subcommittee. It is my pleasure to give testimony today on the nationwide scientific effort called the national superconduction supercollider reference designs study.

Mr. Fuqua. By the way, your statement is not very long, but if any of the panelists wish to insert their testimony and summarize, we would be delighted to do that.

Dr. Tigner. I would like your permission to do that, sir.

Mr. Fuqua. Without objection, it is granted.

Dr. Tigner. While I am asking permission, I would also like to be able to project a few transparencies. Would that be all right?

Mr. Fuqua. Certainly.

Dr. Tigner. As you heard in testimony last October 19 here, the U.S. high energy physics community, through its advisory group to the Department of Energy, the HEPAP panel, gave its highest priority to exploration of a new forefront accelerator concept called the superconducting supercollider. At that hearing, Dr. Sandweiss, chairman of HEPAP, and Dr. Wojcicki, who chaired the most recent HEPAP subpanel on new facilities, described the physics potential of such a facility.

Conceptually, the SSC consists of two rings of superconducting magnets in which counterrotating beams of protons would each be accelerated to 20 TeV and made to collide at specified interaction regions. The energy carried by protons in each beam would be about 20 times that expected in the Fermilab's Tevatron, which is now the world's highest energy particle accelerator and the first such machine operated with superconducting magnets. The SSC ring size would be correspondingly about 20 times larger.

May I show the first transparency? Looking from top to bottom, you can see that in fact the SSC as now conceived is not one but a cascade of accelerators, the smallest of which is barely discernible at the upper center of the drawing. It is called a 50 GeV booster. The particles accelerated there are then shot into the next stage of the cascade, the one TeV booster, where they go into the main ring, which takes up the majority of the picture.

20 TEV Collider

Schematic Plot Plan
No Scale

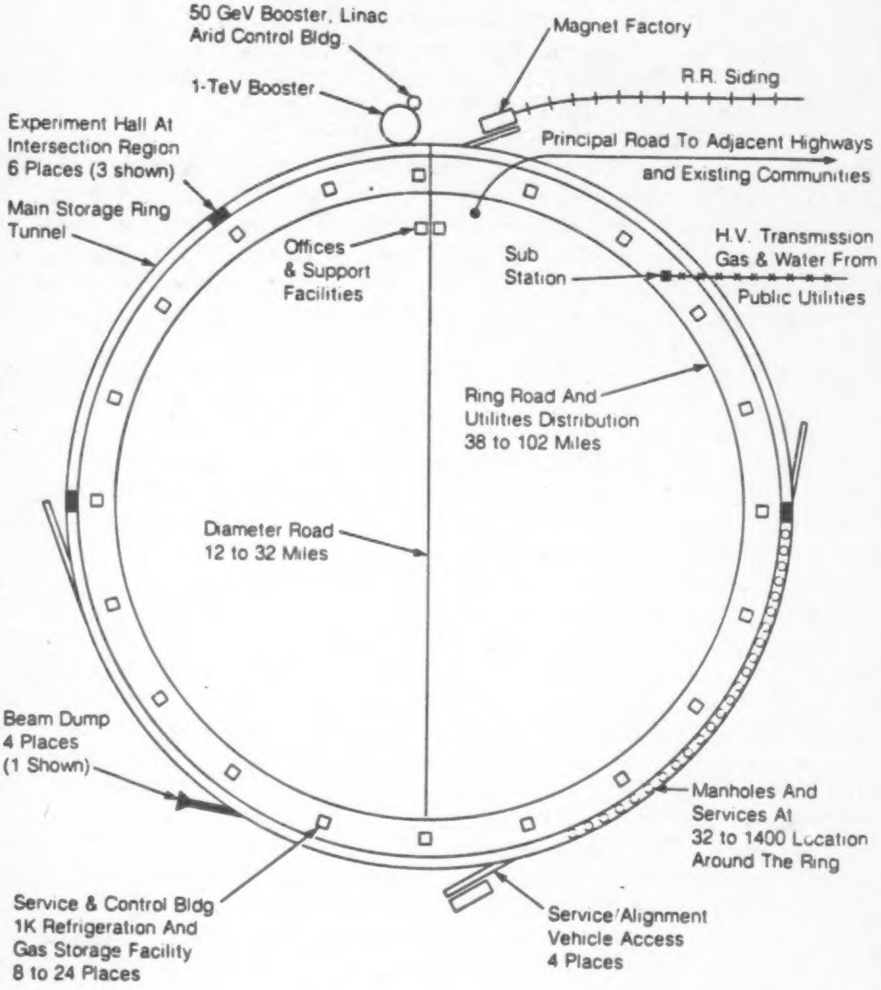

50 GeV Booster, Linac
Arid Control Bldg.
Magnet Factory
R.R. Siding
1-TeV Booster
Experiment Hall At
Intersection Region
6 Places (3 shown)
Principal Road To Adjacent Highways
and Existing Communities
Main Storage Ring
Tunnel
Offices
& Support
Facilities
Sub
Station
H.V. Transmission
Gas & Water From
Public Utilities
Ring Road And
Utilities Distribution
38 to 102 Miles
Diameter Road
12 to 32 Miles
Beam Dump
4 Places
(1 Shown)
Manholes And
Services At
32 to 1400 Location
Around The Ring
Service & Control Bldg
1K Refrigeration And
Gas Storage Facility
8 to 24 Places
Service/Alignment
Vehicle Access
4 Places

FIGURE 1

To give you an even more concrete idea of the size of this facility, I would like to show the next transparency. You might note that the beltway which goes around Washington is just about the same circumference as the main ring of this proton collider. If you would, please, superimpose that first one on top and show that right just about fits on the Beltway. This is not a proposal, Mr. Chairman, to build this machine here in Washington, D.C.

Mr. CARNEY. Will we have a traffic problem getting from the beltway to the middle, like we do here?

Dr. TIGNER. This will improve it, I am sure.

Preconstruction activities in construction of this accelerator are expected to take on the order of 10 years, give or take a couple of years, with 3 or 4 years devoted to advanced accelerator R&D development and engineering studies aimed at establishing a cost-optimized design for the facility. Part of the 1984 advanced accelerator research and development activities, this reference design will lead directly into the serious preproposal R&D.

Provision of such a facility for use by the U.S. scientific community will require extensive cooperation among physicists and engineers in universities, national laboratories, and industry, between the DOE and the scientific community. The national reference designs study already represents such a cooperative effort, involving as it does some 40 scientists and engineers from several national laboratories and universities.

Its primary objective is to help the DOE, the high energy physics community, and the scientific community as a whole to decide how best to proceed with SSC research and development that would be directed toward improving the cost effectiveness of current accelerator technology. The report of the reference designs study will contain technical designs featuring a range of possible technologies. In addition, detailed cost estimates will be included to give the range within which we may reasonably expect the SSC cost to fall. The study will be completed at the end of April of this year.

Since 1978, considerable attention has been given worldwide through open scientific meetings to the basic idea embodied in the SSC. In addition to the HEPAP activities discussed earlier, other recent activities and accomplishments that provide significant input into the reference designs study and, indeed, the idea of the SSC, I will list for you briefly.

There was a major meeting in the summer of 1982 of the American Physical Society and its division of particles and fields held at Snowmass, Colo. In that meeting, the physics that we need to address in the timeframe of such an accelerator, the apparatus for doing that physics, and the accelerator itself were studied in some detail.

In 1983, again the division of particles and fields held a major workshop at the Lawrence Berkeley Laboratory to discuss the kinds of apparatus that one would use to do physics in that sort of area.

Again in 1983, a technical workshop on how to build such an accelerator was held at Cornell University. In 1983, again, the division of particles and fields held an extensive workshop on accelerator physics issues for such an accelerator, and in 1984, just a few days ago in fact, a cryogenic workshop on the accelerator itself was held in Brookhaven National Laboratory.

One could ask why the physics community is so sure that an accelerator of this magnitude can be built. The answer lies in the years of research and development under the sponsorship of the Department of Energy's Division of High Energy Nuclear Physics that have gone into perfecting the basic superconducting technology as it is used with these accelerators. This investment has paid off handsomely during the last year, when Director Leon Lederman and his colleagues at the Fermi National Accelerator Laboratory brought into operation the energy saver, the world's first high-energy accelerator based on superconducting magnets.

The next transparency, please. This is a picture in the tunnel of the Fermilab main ring. The original Fermilab accelerator of conventional copper and iron magnets is the upper orange-painted ring, and the superconducting accelerator, which has been crammed into the space below the ring, can be seen below. It works. It is wonderful.

In addition to this great accomplishment of making a full-blown accelerator work, superconducting magnets of accelerator quality have also been produced at Brookhaven National Laboratory and at the Lawrence Berkeley Laboratory.

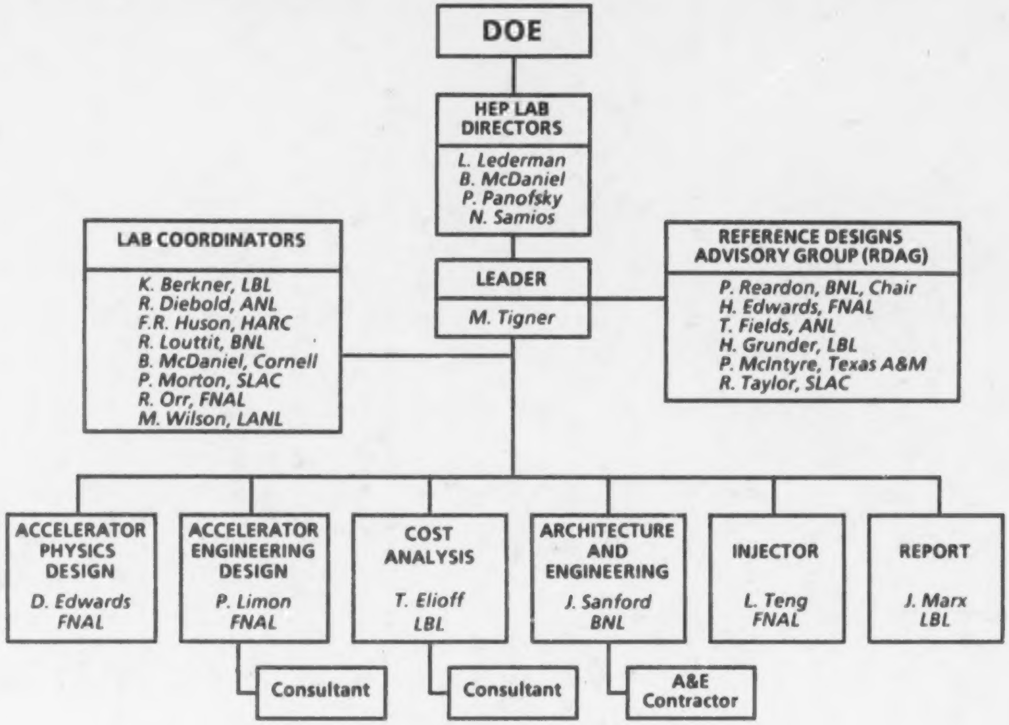
So, our confidence stems from actual success in research and development and engineering activities. Why, then, should we have R&D for an SSC? Why not just go ahead and build more of the same, build a larger version of what we already know how to do? The answer is simple. It would not be very cost effective, knowing what we know today. We can already see ways to save in building a 20-TeV collider. For example, the beams of particles in such a high-energy machine are much smaller than those in the lower energy machines. So we could make the magnets and the beam tubes through which the particles go smaller, thereby saving money.

In addition, we now know how to save substantial labor costs on building such magnets by making much longer units. And we have already made improved superconductor and we intend to incorporate that into the new design.

Several technical approaches are being considered, based on magnet designs put forth at national laboratories and universities which take into account the overall cost optimization of a complete collider. The reference designs study is addressing the technical feasibility of these approaches and estimating their potential cost savings.

Let me turn next to the reference designs study itself. About 40 scientists from seven institutions are working on this effort, with the Lawrence Berkeley Laboratory playing host for the activity which will last until the 30th of April. May I have the last transparency, please? There you see the organization chart of how this work is being carried out. The manpower is actually being donated by the directors who are in the top box there, under the DOE, and I am getting lots of advice from the laboratory coordinators and the advisory group, who are actually helping provide direct contact with the workers in the laboratories who are helping out. The burden of the actual work is being carried by the six groups you see down below, each led by a leading scientist from one of our national laboratories.

SSC REFERENCE DESIGNS STUDY ORGANIZATION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M. Tigner
REFERENCE DESIGNS ADVISORY GROUP (RDAG)
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ACCELERATOR PHYSICS DESIGN
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T. Elioff
LBL
ARCHITECTURE AND ENGINEERING
J. Sanford
BNL
INJECTOR
L. Teng
FNAL
REPORT
J. Marx
LBL
Consultant
Consultant
A&E Contractor

FIGURE 2

Our charter is an ambitious one, addressing three key areas. First, technical feasibility. We are exploring the technical or physics designs of the 20 TeV proton-proton collider, using three superconducting magnet types—low, mid- and high-field options—being developed by several research groups around the country.

We are looking into the economic feasibility. We are analyzing the likely cost range for engineering designs, actual magnets, and other hardware, and conventional facilities required to construct and operate a technically feasible collider. We are also looking into the R&D needs. We are looking into the scope, where the detailed research and engineering development which will be needed to realize the cost-optimized designs which we hope to come up with during phase I.

Let me amplify my comments for just a few moments about the three magnet types and the economic feasibility study. As a result of workshops and meetings which I discussed briefly above, there exists a fair measure of agreement on a rough list of primary parameters for the design of a 20 TeV proton-proton collider. I am speaking about the beam energy, luminosity, collision rate that is, the injection energy, and other basic parameters of the accelerator.

The laboratory directors who are overseeing the activity further suggested that reference designs be based on three values of magnetic field. We expect to be supplied with designs for superconducting magnets, including the cryostats, by the proponents of each of these magnet systems. These proponent organizations are a BNL/LBL collaborative effort, bringing forward the high-field version; the Fermi National Accelerator Laboratory, with a mid-field version; and the Houston Area Research Council, with a low-field option.

Accelerator physicists in the study will carefully review each magnet design before preparing the technical design for a collider based on that magnet. The reference design report will include at least one integrated self-consistent SSC facility design, with a cost estimate and an estimate of the range of uncertainty involved in that estimate. A common cost analysis is being done by the study personnel to put all the costs on the same footing.

Conventional facilities and site utility design is being carried out by a firm of consulting engineers under the direction of the reference designs group.

In making three reference designs, many common elements will be used, such as the injector, the general laboratory facilities, and the tunnel cross section. The work is well underway, and we are thankful to the various laboratory directors, the Department of Energy, and this subcommittee for encouragement and support. The challenges seem formidable but well within our country's capabilities. Thank you for your attention.

[The prepared statement of Dr. Tigner follows:]

REFERENCE DESIGNS STUDY FOR THE SUPERCONDUCTING SUPER COLLIDER

M. Tigner

Cornell University

Testimony before the House Subcommittee
on Energy Development and Applications

February 22, 1984

Chairman Fuqua, members of the Subcommittee, it is my pleasure to give testimony today on the nationwide scientific effort called the National Superconducting Super Collider Reference Designs Study that I have been asked to lead. As you heard in testimony on October 19, 1983, the U.S. high energy physics community, through its advisory group to the Department of Energy (the High Energy Physics Advisory Panel or HEPAP), gave highest priority to a new forefront accelerator called the Superconducting Super Collider (SSC). At that hearing, Dr. J. Sandweiss, chairman of HEPAP and Dr. S. Wojcicki, who chaired the HEPAP Subpanel on New Facilities, described the physics potential of such a facility and recounted the steps in reasoning which led U.S. high energy physicists to give the SSC top priority.

Conceptually, the SSC consists of two rings of superconducting magnets in which counter-rotating beams of protons would each be accelerated to 20 trillion electron volts of energy and made to collide at specified interaction regions. The energy carried by protons in each beam would be some 20 times that expected in Fermilab's Tevatron, which is now the world's highest energy particle accelerator and the first such machine operated with superconducting magnets. The SSC ring size would be correspondingly 20 times larger (Fig. 1). Preconstruction activities and construction of this gigantic accelerator are expected to take 10 years, give or take two, with the first three to four years devoted to advanced accelerator research and development and engineering studies aimed at establishing a cost-optimized design for the facility. Congress has authorized reprogramming of FY1984 accelerator research and development funds, and the National Reference Designs Study that I will describe today is a part of that redirected effort.

Provision of such a facility for use by the U.S. scientific community will require extensive cooperation among physicists and engineers in universities, national laboratories and industry, and between the DOE and this scientific community. The National Reference Designs Study already represents such a cooperative effort, involving as it does some 40 scientists and engineers from several national laboratories and universities. Its primary objective is to help the DOE, the high energy physics community and the scientific community as a whole to decide how best to proceed with SSC research and development that would be directed toward improving the cost effectiveness of current accelerator technology. The report of the

Reference Designs Study will contain technical designs featuring a range of technologies that might be used. In addition, detailed cost estimates will be included to give the range within which we may reasonably expect the SSC cost to fall. The study is to be completed in May 1984.

Since 1978, considerable attention has been given worldwide through open scientific meetings to the basic idea embodied in the SSC. In addition to the HEPAP Subpanel's extensive discussions in Woods Hole last June, the other recent activities and accomplishments that provide significant input into the Reference Designs Study are listed below. Note that the numbers in parentheses indicate the approximate number of scientists involved in each activity.

1. The 1982 Summer Study on Elementary Particle Physics and Future Facilities sponsored by the Division of Particles and Fields (DPF) of the American Physical Society and held at Snowmass, Colorado, June 28-July 16, 1982 (150).
2. The 1983 DPF Workshop on Collider Detectors held at Lawrence Berkeley Laboratory, February 28-March 4, 1983 (80).
3. The Technical Workshop on the 20 TeV Hadron Collider held at Cornell University on March 28-April 2, 1983 (40).
4. Physics at the SSC (PSSC) Meetings held monthly since September 1983 at various universities and laboratories (200).
5. The 1983 DPF Workshop on Accelerator Physics Issues for the SSC held at the University of Michigan, Ann Arbor on December 12-17, 1983 (70).
6. The 1984 DPF Cryogenic Workshop held at Brookhaven National Laboratory on January 17-19, 1984 (100).

One could readily ask why this physics community is so sure that such an accelerator can be built. The answer lies in the years of research and development under the sponsorship of DOE's Division of High Energy and Nuclear Physics that have gone into perfecting superconducting accelerator magnets and associated technologies. This investment paid off handsomely during last year when Director Leon Lederman and his colleagues at the Fermi National Accelerator Laboratory brought into operation the Energy Saver (or Tevatron), the world's first high-energy accelerator based on superconducting magnets. In addition, accelerator-quality superconducting magnets have also been produced at the Brookhaven National Laboratory and the Lawrence Berkeley Laboratory.

So the physicists' confidence stems from actual successes in research and development activities. Why, then, have a Reference Designs Study? Why not just funnel all the available resources into building a larger version of what we already know how to do? The answer is straightforward - it would not be the most cost-effective solution, knowing what we know today. We can already see ways to save in building a 20 TeV collider. For example, the beams of particles are smaller in cross section at higher energies, so we would like to make the beam tubes as small in diameter as possible. This would reduce the cross section of the magnets through which they pass and therefore minimize the amount of expensive superconductor and other materials needed to fabricate the magnets. We have also learned that a major magnet labor cost has to do with the magnet ends where the superconducting coils and cryostats end and connections must be correctly fitted and sealed. Therefore, we want to make the magnets as long as possible. Also, improved superconductors may be available very soon and should be incorporated. Several technical approaches are being considered based on magnet designs put forth at national laboratories and universities which take into account the overall cost optimization of the complete collider. The Reference Designs Study will address the technical feasibility of these approaches and estimate their potential cost savings.

Let me turn next to the Reference Designs Study now underway and destined to become history in three short months. About 40 scientists from seven institutions are working on this effort, which the Lawrence Berkeley Laboratory has agreed to host (Fig. 2). Our charter is an ambitious one, addressing three key areas:

- Technicial feasibility - Explore the technical (physics) designs of 20 TeV proton-proton colliders using three superconducting magnet types (low-, mid-, and high-field options being developed by several research groups around the country).
- Economic feasibility - Analyze the likely cost range for engineering designs (actual magnets and other hardware) and conventional facilities required to construct and operate a technically feasible collider.

- Cost demonstration - Scope out the detailed research and engineering development needed to realize the cost optimization of designs based on technologies currently in hand.

Let me amplify my comments about the three magnet types and the economic feasibility study.

As a result of the workshops and meetings listed above, when the Reference Designs activity began there existed a fair measure of agreement on a rough list of primary parameters for the design of a 20-TeV proton-proton collider. I'm speaking here about the beam energy, luminosity (collision rate), injection energy, and other basic parameters of the accelerator. The Laboratory Directors who are overseeing the activity further suggested that reference designs be based on three values of magnetic field corresponding to the fields developed in the magnet designs put forth by research teams around the U.S.. We expect to be supplied with designs for superconducting dipole (bending) magnets, including cryostats, by the proponents of each magnet system. These proponent organizations are - a BNL/LBL collaborative effort (high field), Fermi National Accelerator Laboratory (mid field), and Houston Area Research Council (low field).

The accelerator physicists in the Study will carefully review each magnet design before preparing the technical (physics) design for a collider based on that magnet. The reference design report will include at least one integrated self-consistent SSC facility design with a cost estimate and an estimate of the range of uncertainty involved in that estimate. A common cost analysis is being done by Study personnel to put all costs on the same footing.

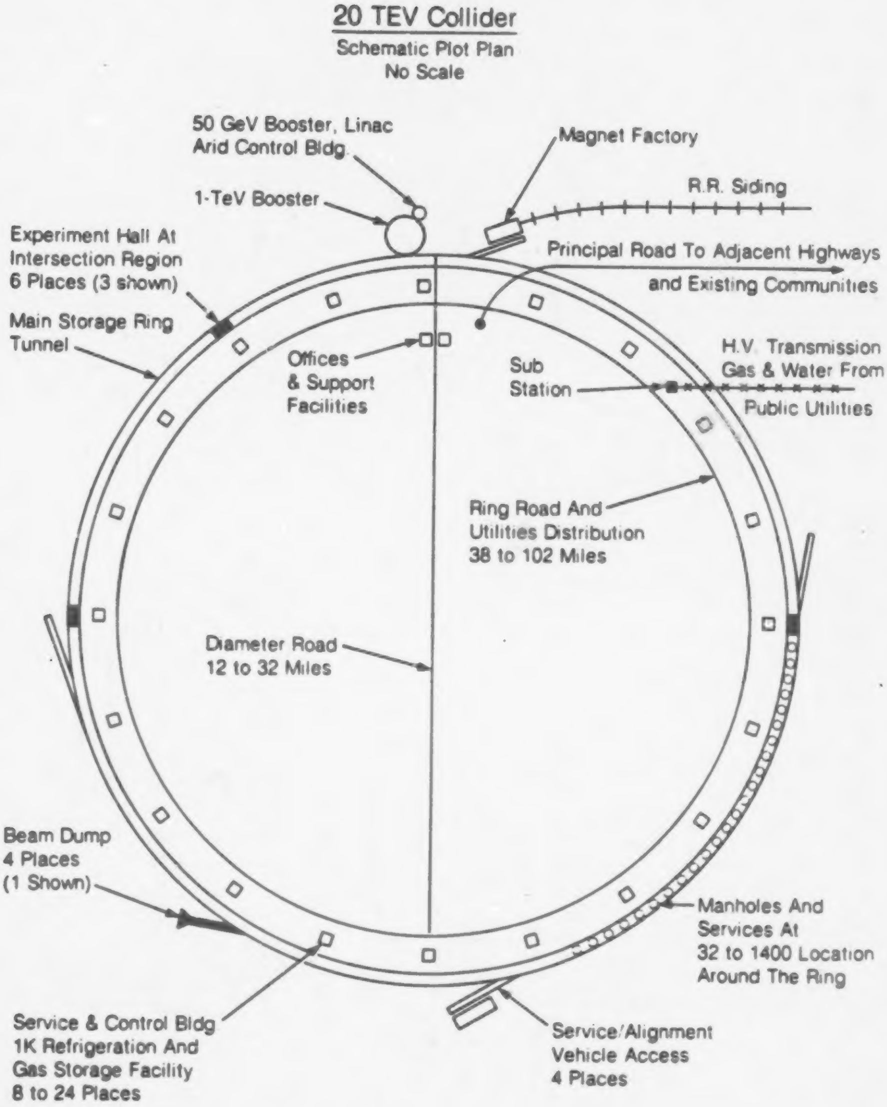
Conventional facilities and site utility design is being carried out by a firm of consulting engineers under the direction of the Reference Designs Group. The conventional facilities will include the normal complement of offices, laboratories, shop buildings and other support facilities necessary for doing physics with the accelerators, as well as the actual intersection region experimental halls and accelerator structures. Cost estimating for these facilities will be carried out by the A.E. firm, supplemented by the efforts of specialized cost consultants if necessary.

In making the three reference designs, many common elements will be used (such as the injector, the general laboratory facilities, and the tunnel cross sections).

The main purpose in doing this is to reduce the effort involved in making multiple reference designs. Taking this approach will mean that cost differentials between the estimates for different reference designs may not be a reliable guide to the cost differentials to be obtained in later, more optimized designs. In the same spirit, the Reference Design Studies will not include estimates of "options" which would broaden the scientific scope of the facility such as the slow extraction of proton beams from the accelerator for fixed-target experimental studies, or the construction of an antiproton source or an auxiliary electron accelerator which would make possible collisions between antiprotons and protons or between electrons and protons, respectively.

This work is well underway, and we are thankful to the various laboratory directors, the Department of Energy, and this Subcommittee for encouragement and support. The challenges seem formidable, but well within our country's capabilities. I would be pleased to answer any questions about the National Reference Designs Study.

Dr. Maury Tigner is a professor of physics at Cornell University and manager of the Robert R. Wilson Synchrotron Laboratory. His research specialty is the design and development of new particle accelerators.


20 TEV Collider
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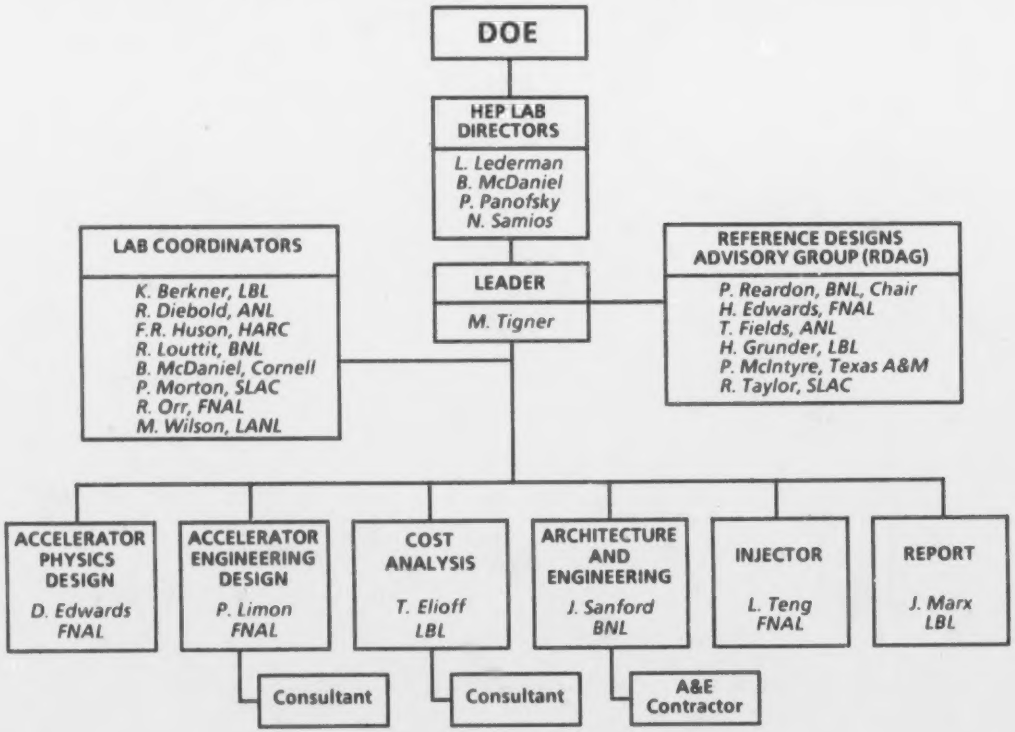
Tunnel
Offices
& Support
Facilities
Sub
Station
H.V. Transmission
Gas & Water From
Public Utilities
Ring Road And
Utilities Distribution
38 to 102 Miles
Diameter Road
12 to 32 Miles
Beam Dump
4 Places
(1 Shown)
Manholes And
Services At
32 to 1400 Location
Around The Ring
Service & Control Bldg
1K Refrigeration And
Gas Storage Facility
8 to 24 Places
Service/Alignment
Vehicle Access
4 Places

FIGURE 1

SSC REFERENCE DESIGNS STUDY ORGANIZATION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L. Teng FNAL
REPORT
J. Marx LBL
Consultant
Consultant
A&E Contractor

FIGURE 2

Mr. Fuqua. Thank you very much.

Dr. Lederman, we are pleased to have you here today. We will be pleased to hear from you.

STATEMENT OF DR. LEON M. LEDERMAN, DIRECTOR, FERMI NATIONAL ACCELERATOR LABORATORY, BATAVIA, ILL.

Dr. Lederman. Thank you, Mr. Chairman. I would like to ask permission to present for the record my formal remarks.

Mr. Fuqua. Yes, without objection, we will do that, and you may summarize, if you desire.

Dr. Lederman. I would like to thank you for inviting me. It is a pleasure to testify here. It is a special pleasure because when it was known that I was going to testify, my wife went out and bought me this new suit that you must all be admiring.

Mr. Fuqua. As always, she has good taste.

Dr. Lederman. I would like to tell you a little bit about the status of the Tevatron. Some of the preceding speakers have already mentioned this project.

Tevatron, in general, covers three construction projections: The energy saver, the superconducting ring, Tevatron II and Tevatron I. The DOE is not trying to emulate NASA by counting backwards, but that is the way it works out: II comes before I.

July 3, 1983, was an historic occasion in the history of accelerators. The first superconducting accelerator, 4 miles around, accelerated particles to 512 billion electron volts, 512 GeV. This was the culmination of about 6 years of R&D at Fermilab, in turn based on previous efforts at Argonne, at Brookhaven, at the Rutherford Lab in England, and at some of our high tech industries like Bell Labs and Westinghouse.

The process of learning how to make superconductor cable and all the other pieces that go into an accelerator magnet took many years. We had to acquire all the special components, often by intimate interaction with vendors, and assemble 1,200 large superconducting things. It was a process of natural technology transfer, since our people learned, at the same time that the industrial vendors learned, how to get the proper product. We had to assemble the world's largest cryogenic plant and make it deliver 24,000 watts of refrigeration to cool the ring to 4.7 degrees. Fifteen years ago 300 watts was a spectacular refrigerator.

We had to design and implement a fantastic system of computerized controls, with over 700 resident intelligences and microprocessors, organized to manage a complex system.

Construction started on July 9, 1979, and last July 3 it all came together and it worked. On October 1, we started a physics program at the modest energy of 400 billion volts, hoping that this would greatly simplify the running in of this very young and very complex accelerator. Last week, February 14, we terminated the run as planned, and during this interval of time, we completed five important experiments which required that modest energy, and we provided two test beams for users to calibrate equipment. We amassed a great deal of data on the properties of the machine and gradually raised the operating efficiency to about 80 percent. We thoroughly tested all the many safety features of a superconducting accelerator, and we tested them more thoroughly than we planned because a site-wide power failure 2 weeks ago turned off all of our electricity—even my wristwatch—and it was gratifying that the machine came on within 20 hours.

We learned how to store beam for 30 hours, which was needed for the Tevatron I program. We gradually increased the intensity of protons from about two times ten to the 12th to over one times ten to the 13th protons for every pulse. We learned how to improve the time structure of the beam so that 1 hour of time at the energy saver was equivalent to 4½ hours of time on the old machine.

On February 14, we began a 3-day period of testing at higher energy, and as you have heard, on the 17th we reached 800 GeV and succeeded in extracting this to the experimental area. We further exercised the magnets without beam to 825 GeV to test for weak parts of the machine. All of this is very gratifying. We are now in a 3-week shutdown period to install devices which we need for Tevatron I. We will begin the second physics run with an energy of 800 GeV, which will continue until July 1 of 1984. When we next turn on, I hope it will be extremely close to 1,000 GeV.

To implement the energy saver, to do physics with it, we have these two other programs. Tevatron II is a construction project which must upgrade all of the beam lines—and there are 14 such beam lines—to handle 1,000 GeV particles. Four of the five experiments I just mentioned were in new Tevatron II beam lines. The project is about 55-percent complete. It is on schedule, and I am on budget insofar as the construction funding is concerned.

Tevatron II will be implemented gradually. The last beam line is expected to be complete in 1986. We do have a problem with equipment funds, which are part of the total project cost.

Tevatron I uses the energy saver in the collider mode. The collider mode was described by Dr. Tigner. In Tevatron I we must create a very intense source of heretofore very exotic particles, antiprotons. We must inject antiprotons into the energy saver at the same time that protons are circulating in the opposite direction. The saver will then accelerate both beams to 1,000 GeV, and by the aid of special focusing magnets cause them to collide in two places where detectors can observe these collisions.

This project is about 4 months behind schedule, about 40 percent complete, and is on budget. The first scheduled physics run is about mid-1986.

Let me say a few words about how these machines will add to the science of high energy physics. Tevatron II is a programmatic study of the quark structure of matter. Since quarks are observed only in the bound state, it takes a wide variety of measurements before we can assemble a complete and quantitative picture of the properties of these basic building blocks of matter.

Tevatron II provides Fermilab users with a variety of secondary beams—protons, antiprotons, pions, kaons, sigmas, photons, muons, neutrinos—as probes of this fundamental structure. Tevatron II is unique in the world. It will be far ahead of our CERN friendly rivals, who have only 400 or perhaps 450 billion volts available, and it will continue to be unique at least until the Soviet machine, UNK, comes in sometime in the 1990's.

Over 600 physicists and students from universities in the United States and abroad are involved in this program. Tevatron I is an exploratory, discovery machine. Its 2,000 GeV will be the highest energy in the world, until the Soviet collider, which will be sometime in 1995 or, much more hopefully, the SSC appears. Here, theoretical predictions have to be speculative. It is a domain where strange, exotic particles too numerous to list have been suggested.

Sir, the Tevatron was not an easy machine to build. It is probably the most technologically sophisticated particle accelerator ever constructed. But it seems to work, and our people are bursting with ideas as to how they can do better, and some of these ideas Professor Tigner talked about, how you can do better after you have done it once. We have a fantastic two-edged instrument. One edge is systematic, accurate, programmatic studies—that is Tevatron II. The other edge is exploratory, sort of a salient into the unknown—that is Tevatron I.

On behalf of my colleagues at Fermilab, I would like to thank this committee for your support in making all of this possible.

[The prepared statement of Dr. Lederman follows:]

Statement of Leon M. Lederman
House Committee on Science & Technology
Subcommittee on Energy Development & Application
Hearings on High Energy Physics
February 22, 1984

THE ENERGY SAVER

On July 3, 1983 at 3:37 p.m., Fermilab's Energy Saver first accelerated particles to an energy of 512 GeV. (Billion electron-Volts). The world's first superconducting+ synchrotron accelerator went into operation after some six years of R&D and four years of combined R&D and construction.*

Three months of commissioning followed and on October 1, 1983, the TEVATRON physics program was initiated with five major experiments taking data and two "test beams" in full use for testing and calibration of detection devices. In the commissioning phase, acceleration to over 700 GeV was achieved and the enormously sophisticated computerized controls were given full testing as were the elaborate safety systems.

We initiated the science program at a very modest energy of 400 GeV in order to have a long period of "running-in" of this very novel accelerator without the additional complication of very high current operations. Also, the scientific program was well served since we had several important research projects that required this energy. In the period October 1 - February 14, we completed all five experiments and devoted considerable time to putting the accelerator through its paces.

+ A "PRIMER ON SUPERCONDUCTIVITY" is attached as Appendix I.

* This turned out to be quite a media event, making front page in the New York Times, Washington Post and newspapers around the country. Several editorials commented on the event. It was covered on national TV and reviewed on ABC's "Nightline." One strong impression from the wide interest in a rather exotic scientific happening is that the success tended to restore some of the luster to U.S. technology, badly shaken by European and Japanese competition.

In the past week, (Feb. 14-17) before a shutdown to install components for TeV I, we successfully accelerated beam to 800 GeV and extracted this to the experimental areas. This is a major milestone in the evolution of the Energy Saver towards 1000 GeV (TEVATRON) operation. Let me make another comment about the name Energy Saver: our old 400 GeV program used 43 Megawatts of pulsed power; the new ring; at more than twice the particle energy, will only use 3 Megawatts of pulsed power. [Another 10 MW is used for refrigeration, so the electrical power savings aren't that spectacular]. I am pleased to report that this savings is still slightly ahead of the increased costs of electrical power. Put another way, had we not gone superconducting, electrical power costs would have severely limited our scientific program.

A chronological table of SAVER milestones is given below. Although the credits for these achievements go to too many individuals to list here, it is important, for the record, to give you some of the leading figures. They are:

R. R. Wilson	Founding Director of Fermilab - who conceived the idea of the Energy Saver and directed the early R&D phase.
Alvin Tollestrup	Came to Fermilab from Caltech for a Sabbatical and stayed to become the leading problem solver in the magnet R&D program.
Helen Edwards J. Ritchie Orr	Co-Directors of the Energy Saver construction program. They had to think of everything and apparently, they did!
Richard Lundy	Manager of the magnet assembly facility which assembled, tested and quality assured over 1400 superconducting devices.
William Fowler Claus Rode	Designed and constructed the world's most advanced and most massive cryogenic plant for the production of liquid helium.

Energy Saver Chronology

1967-1970	Discussions of adding superconducting magnets to ring. Decision: No!
3-71	Wilson announces intention to request authorization to build Energy Doubler.
9-72	Working group established.
1-73	R&D started.
4-73	First short magnet tested.
5-73	First preliminary design report (TM-421).
1-74	Energy Doubler Design Study Progress Report.
5-75	Beam transported through one 3-ft magnet at B12. Magnet hung on tunnel ceiling.
7-75	Central Helium Liquefier Satellite concept developed.
8-75	Beam quench studies on early superconducting magnet in A0 extraction line.
12-75	External collar concept developed.
2-76	B12 above-ground test area started.
1976	About ten 22-ft magnets made.
1977	B12 test area-four magnet string test started 2000 A.
12-78	Beam transported A0 to A17, 22-ft magnets (20 dipoles, 3 quads).
5-79	Final design report-change magnet design length to 21 ft.
6-79	B12 test area-16 22-ft magnets, 4 quads installed.
7-79	Start of construction.
12-80	Start installation of A-sector.
1-81	B12-test area-16 21-ft magnets, 4 quads, installation starts.
3-81	B12 test area-start tests on final magnets.

5-81 12-81	Installation of 3/4 A-sector.	
1-82 6-82	3/4 A-sector test to 4200 A	Cryogenics Power Voltage-to-Ground Quench Protection Pressure Tests
6-82	Beam transported through injection system at E0 and 400 GeV program terminated. Installation shutdown starts.	
3-83	Last magnet installed in ring.	
5-83	Entire accelerator cooled to Liq Helium.	
2 June 83	First full turn of beam around machine	
26 June 83	Many turns: coasting beam	
3 July 83	Acceleration to 512 GeV	
2 Aug 82	Extraction to Experimental Areas	
15 Aug 83	Acceleration to 700 GeV	
1 Oct 83	Begin Physics Program	
16 Oct 83	Storage for over 30 hours	
14 Feb 84	First running period terminated	
14 Feb 84	Acceleration and Extraction at 750 GeV.	
16 Feb 84	Acceleration and Extraction at 800 GeV.	

In Appendix II we give additional information on the startup of the Energy Saver written by Dr. Helen Edwards, Co-project Leader.

THE TEVATRON PROGRAM

Now I would like to tell you how we plan to apply the Energy Saver to carry out basic research in High Energy Physics. Our program is invested in two construction projects: TEVATRON II and TEVATRON I.[+]

TeV II involves extracting the accelerated beam from the machine and sending it to the Experimental Areas. On the way, the beam is split three ways, each subbeam is split again, targets are struck and the resultant nuclear debris is organized into secondary and tertiary beams. As a result (See Figure 1) we have fourteen beam lines serving (in principle) fourteen simultaneous experiments. In these experiments particles strike fixed targets and the results of these collisions are examined by very sophisticated detection equipment. The TeV II construction program upgrades and modifies these beam lines to handle 1000 GeV beams. Along with the construction, there is the equipment that must go with defining the beam lines and actually doing the experiments.

TeV I involves using the collider mode for carrying out observations at extremely high energies. Here, one must build an antiproton ($\bar{p}$) source of sufficient strength to enable the acceleration of a significant number (100 billion) of those fairly exotic particles to the full energy of the SAVER. Antiprotons carry a negative electric charge and therefore circulate in the opposite sense to protons in the same accelerator ring. This permits one to organize head-on collisions of protons and antiprotons, each having the energy of 1000 GeV. Although the number of collisions per second is relatively low

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[+] DOE is not emulating NASA by counting backwards, it just worked out that way.

(it's like two machine guns firing at each other and watching for bullets to collide) it turns out that the effective energy of such collisions is 500 times that of a 1000 GeV proton hitting an atomic nucleus at rest. Our (friendly) rival lab in Geneva, CERN, has pioneered such colliders and last winter made several spectacular discoveries by their use.

Let me give you the bottom line on our progress. TeV II started limited operation (as we mentioned above) on October 1. The project, with about 50% of its funds committed, is on schedule with its contingency somewhat bruised but still intact. It will not overrun. TeV I involes the $\bar{p}$ source and storage of particles in the SAVER ring for longer than ten hours. WWe have recently stored 800 GeV; the energy will gradually be increased as operating experience is gained. The project is about 40% complete, still has a healthy cntingency and is about four months behind its original schedule.

PHYSICS OF TEV II: QUARKS AND LEPTONS

The 1000 GeV TeV II (fixed target) research will be unique. CERN's SPS machine is operated at 400 GeV. The Soviets have a 3000 GeV machine under construction, but as far as I know it is not expected to operate before the early 1990's. The main thrust of TeV II is a systematic and programmatic onslaught on the quark structure of matter or what we call constituent physics. Since quarks are never observed in the free state, our knowledge of their properties, forces, how they interact and how they decay is indirect and therefore we need very quantitative data from a wide variety of types of probes. TeV II will provide the following bombarding particles to probe the quark structure: protons, antiprotons, pions, kaons, sigmas, photons, muons, neutrinos and polarized protons. It is this variety which should give us an incisive picture of nature at the quark level.

The energy of 1000 GeV opens up a very significant domain for the study of how quarks jiggle and clump and decay and scatter. Over six hundred physicists (150 from abroad) have been approved to carry out some 25 experiments over the next three-four years. These are listed below. (Appendix III)

PHYSICS OF TEV I

Coming three years after CERN's collider, TeV I must be much better. It is. We will have four times the energy in the center of mass of the collision as the present CERN collider. We hope to have ten times the collision rate (luminosity) as the present machine. We do expect CERN to improve somewhat but if we work hard and if we are good, we should exceed our own specs. In any case, TeV I opens up a very broad region to observation - the domain beyond that which our current theory can safely predict and into the domain of speculation. TeV I is a discovery machine although clearly there are many things that one wants to measure. The candidates to be discovered illustrate the desperation of theoretical physics. They go by the names of: technicolor, hypercolor, supersymmetry, monopoles, fourth generation quarks and even: preons, quirks, rishons and so on(s)! Our theoretical friends need help and TeV I wil be the highest energy machine until either the Soviets, the Europeans or we build the Supercollider which my colleague, Professor Tigner, described today.

To carry out the observation of proton-antiproton collisions, we are in the midst of building a Colliding Detector at Fermilab (CDF). The make up of the group is very international (see Appendix IV) with strong Japanese participation (and Yen!!). Another colliding detector of more modest scale is being considered for our second interaction region.

FINAL COMMENTS

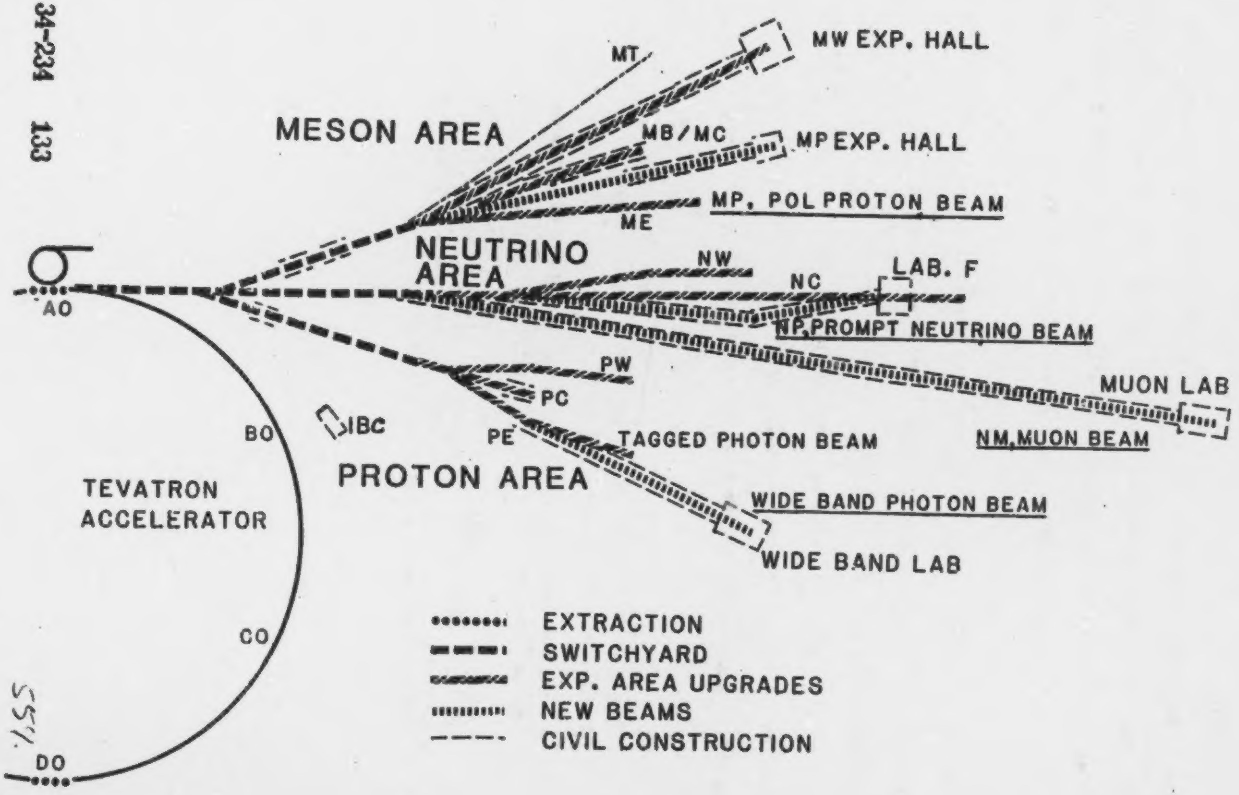
Fermilab is the largest U.S. laboratory. It provides facilities for about 60% of the U.S. user community and is presently host to about 200 scientists from some eighteen countries around the world. We are creating some superb facilities. We are concerned and we can only pray (we have tried everything else!) that the operating and especially the equipment funds will be forthcoming to exploit these facilities with the exuberance which will permit us to help restore U.S. leadership in this frontier science.

Science does not live by quarks alone and our laboratory does have some responsibility for the broader, contiguous societal concerns. I briefly list some of the things we refer to as socially redeeming activities. We will be delighted to supply more information on any of these.

1. Science education: Some nine programs including our now famous Saturday Morning Physics for high school students, Teachers' Institutes, minority students, etc.
2. Technology Transfer - through an Industrial Affiliates program, we have learned how subtle and difficult this is.
3. Developing Countries - we have created a Latin American "institute" to provide hospitality and moral support for scientists from Latin America. We have organized a series of Pan American symposia to improve ties with science in Latin America.

TEV II CONSTRUCTION AREAS

34-234 133


MT
MW EXP. HALL
MESON AREA
MB/MC
MP EXP. HALL
MP, POL PROTON BEAM
ME
NEUTRINO AREA
NW
NC
LAB. F
NP, PROMPT NEUTRINO BEAM
MUON LAB
NM, MUON BEAM
AO
PW
PC
IBC
BO
PE
TAGGED PHOTON BEAM
PROTON AREA
WIDE BAND PHOTON BEAM
WIDE BAND LAB
TEVATRON ACCELERATOR
CO
DO
EXTRACTION
SWITCHYARD
EXP. AREA UPGRADES
NEW BEAMS
CIVIL CONSTRUCTION

55%

Appendix I

PRIMER ON SUPERCONDUCTIVITY

After 70 years in the world of university physics laboratories, superconducting technology has begun - tentatively - to make itself useful in harsher environments. The value of superconductors lies in their ability to transmit huge currents without electrical resistance, and thus sustain intense and extremely steady magnetic fields. These characteristics have prompted many application ideas with possible long-range commercial significance.

Although superconductors were discovered in 1911 (by Dutch physicist Kamerlingh Onnes), they remained strictly research objects for half a century. The persistent failure of early theoreticians to explain how superconductivity works didn't help. Finally, in 1957, J. Bardeen, L. N. Cooper, and J. R. Schrieffer formulated a theory that made sense of the curious phenomenon.

Like solid, liquid, and gas, superconductivity is a state of matter. It exists only within certain limits of temperature, magnetic field, and current density; as soon as any one of these exceeds a critical level, superconductivity vanishes and normal resistance resumes. The early superconductors were pure metals such as mercury and lead that lost their superconductivity in the presence of relatively small magnetic fields and so were not very useful. These metals were therefore readily shelved when better superconductive properties turned up in certain alloys and compounds.

Consider what happens if, for example, we slowly cool a wire of the alloy niobium-titanium (NbTi) - today's most common superconductor and the one used in Fermilab's Energy SAVER magnets. For a while, the wire's electrical resistance declines steadily - just as it would with a conventional conductor such as copper. Then, at about 10 degrees above absolute zero (10 Kelvin), the resistance abruptly vanishes: The wire has entered the superconductive state although even a tiny current or magnetic field applied to the superconductor will nudge it back into the resistive state - an event called "going normal," or "quenching." Cooled further, the NbTi tolerates increasingly large currents and fields without going normal. As temperature approaches absolute zero, the field and current limits become, in the case of NbTi, about 15 tesla and 10^6 amperes per square centimeter.

In the course of the R&D program to develop the superconducting magnets for the Tevatron, Fermilab played a very prominent role in stimulating industry to develop its superconductivity skills. Approximately 150,000 lbs of a once exotic niobium titanium superconducting alloy was used in creating the Tevatron. Other uses of superconductivity are in fusion research, in medical imaging via NMR devices, in experimental levitated trains, isotope separation, sewage treatment, etc., etc.

Appendix II

STARTING UP THE ENERGY SAVER

Helen Edwards

Introduction

The Energy Saver has occupied a large part of the attention of many Fermilab people for some years. All this work reached a climax in 1983. Installation was complete and cooldown of the final sector began in May. Beam was first injected into the completed Energy Saver Superconducting Accelerator on June 2, accelerated beam was first achieved on July 3, and resonant extracted beam first sent to the Beam Switchyard Area on August 2. A new energy record of 700 GeV was reached on August 12, during the 12th International Conference on High-Energy Accelerators. These events were the culmination of ten-and-a-half years of R&D, tests, construction, and installation of the new accelerator system in the Main-Ring tunnel. The final goal of a 800 to 1000 GeV proton beam at approximately 2×10^{13} ppp for fixed-target physics and $\bar{p}p$ storage and collision at $10^{30}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ awaits further tuneup and the construction of the $\bar{p}$ source (TeV I), but there is a story to tell of how we got to where we are.

What is Different in This Accelerator?

The use of superconducting magnets in a large accelerator brings with it the necessity for major new engineering systems and their control. Together the magnitudes of the overall amount of equipment, system complexity, and fragility of these new utility-like systems not only dwarf the corresponding components of the conventional accelerator, but also influence their design. The conventional components must also work effectively so that during early stages of commissioning, when overall reliability is not high, progress can be made toward obtaining an accelerated beam.

The superconducting magnets requie a large cryogenic system to supply both liquid helium at 4.7 K and liquid nitrogen. The cryogenic system for the Energy Doubler provides 24 kW of cooling at 4.7 K. This system is larger by several orders of magnitude than any previous one and its smooth operation is a major advance and triumph for its builders.

The Energy Saver magnets require an "active" quench protection system in order that the magnet conductor is not damaged by overheating when a magnet goes normal and "quenches." The active protection system continuously monitors voltage across the magnet cells at about 250 points and detects any resistive component greater than a given threshold. Upon quench detection, three things happen: a) Stainless-steel strips in the magnets adjacent to the coil are heated by discharging capacitors into them, thus causing uniform energy absorption in the quenched cell and reducing overheating at isolated spots; b) the main bus current is diverted around the quenched cell through a bypass circuit external to the cryogenic system; c) the main power supplies are bypassed and dump resistors are switched in order to extract the total ring stored energy (350 MJ at 1000 TeV) with a 12-sec decay time constant. The quench-protection system is a ring-wide system with 24 microprocessors (one in each service building) which are in constant communication with one another. Each is constantly checking the voltage reading from its part of the magnet string. Any missed communication or noise can potentially turn off the magnet power system or quench the magnet accidentally.

The vacuum system for the superconducting magnets is much more complicated than for a standard accelerator. The system consists of an outer insulating vacuum jacket with four isolated inner volumes, each of which must be leak-tight to the insulating vacuum. These volumes are a) the bore-tube high-vacuum region in which the beam runs; b) the single-phase helium space; c) the two-phase helium space; d) the nitrogen-shield space. Not only must one provide pumps and instrumentation for the two separate vacuum systems, but during installation, leak checking must be performed on the four separate internal volumes where the flange joints are not externally available for classical leak-check procedures. One potential advantage is that the beam vacuum bore tube is at low temperature and automatically provides very low pressure.

Because of worry about the feasibility of the operation of the cryogenic system, the quench-protection system, and the vacuum system, special efforts were made early on in order to develop workable engineering plans, both for implementing the systems and for successful installation procedures. Very substantial efforts were required from the electrical engineering and controls groups in order to meet the demands of the "utility systems" on a timescale that allowed for test debugging and refinement of techniques before the scheduled start of beam operation.

Superconducting magnets are sensitive to beam loss and have magnetic-field characteristics different from conventional iron Within the conventional accelerator systems, particular attention has been given to the correction and adjustment coil system and to the beam-position and loss-monitor systems.

The beam-position and loss-monitor systems were planned with the view that one wanted to obtain the most information possible from a single shot of injected beam. If the magnets quenched because of the beam being mis-steered, corrective action could be taken during the quench-recovery time (typically, 10 minutes to 2 hours) and the beam could get further on the next pulse. Special attention was also given to being able to run at very low intensity (10^{10}p) so as to reduce the magnet-quench probabilty. Thus the system was required to be very sensitive and at the same time very flexible, because it must be able to gather and store one-turn information and closed-orbit information at many positions and times through the cycle.

The one-turn position information, coupled with the one-turn abort ssystem, and beam-loss information provided to be very effective in locating obstacles in the aperture and in obtaining correct injection conditions, including guide field setting. The one-turn and closed-orbit information can be relayed to a program that determines dipole correction-coil adjustments. As it turned out, the closed orbit did not change appreciably with excitation, making the problem of accelerating to higher and higher energies less arduous than expected. The ability to abort the beam on loss has been of substantial use in trying to go to higher intensities, especially during extraction studies. The turn-by-turn position information has been of great value, not only at injection time for minimizing coherent oscillations, but also for minimizing injection guide-field mismatch and for doing tune measurements at any excitation with a "pinger" to induce coherent betatron oscillations.

The correction-coil system is composed of corrections and adjustments for steering, tune and chromaticity control, and resonant-extraction control. The system allows for programming control of all circuits from injection to full excitation. It is desirable to be able to center the beam accurately with dipole corrections at any excitation, thus making full use of the available aperture. This is particularly true at extraction time, when the resonant beam is making large excursions. The system allows for any unexpected shift or rotation of the main magnets with excitation, quench, or upon a warm-up/cool-down cycle, without recourse to magnet realignment, which would be somewhat risky to the vacuum integrity. Although the initial magnet-survey alignment and stability of the superconducting magnets so far seem good, the advantages of the full-excitation corrections in operational convenience seem well worth the expense in this machine and in any future large accelerator where strength of superconducting correction is not a problem.

Here again the control system plays an essential role in the success of these sophisticated correction and detection systems. Extensive use of microprocessors to provide local control-curve generation and data storage has been a fundamental feature of these systems.

APPENDIX III

LIST OF CURRENTLY APPROVED FIXED TARGET EXPERIMENTS

E-400 (WISS): CHARM PRODUCTION BY NEUTRONS (COLORADO, FERMILAB, ILLINOIS, MILANO, PAVIA, BOLOGNA, YALE) (25)

E-557 (MALAMUD): HADRON JETS WITH THE MPS (ARIZONA, CALTECH, FERMILAB, FLORIDA STATE, GEORGE MASON, ILLINOIS/CHICAGO, IHEP/SERPUKHOV, INDIANA, MARYLAND, RUTGERS) (47)

E-605 (BROWN): LEPTONS AND HADRONS NEAR KINEMATIC LIMITS (CERN, CEN/SACLAY, COLUMBIA, FERMILAB, KYOTO, SUNY/STONY BROOK, WASHINGTON) (43)

E-609 (SELOVE): HIGH P_T HADRONIC JETS (ARGONNE, FERMILAB, LEHIGH, MICHIGAN, PENNSYLVANIA, RICE, WISCONSIN) (29)

E-615 (McDONALD): FORWARD DI-MUON (CHICAGO, FERMILAB, IOWA STATE, PRINCETON) (33)

*E-621 (THOMSON): MEASUREMENT OF η_{+-0} (MICHIGAN, MINNESOTA, RUTGERS, WISCONSIN) (15)

*E-632 (MORRISON): 15 FT. WITH Ne/H_2 (BIRMINGHAM, BRUSSELS, CEN/SACLAY, CERN, FACCINI, FERMILAB, HAWAII, IIT, IMPERIAL COLLEGE, MPI/MUNICH, OXFORD, TUFTS) (57)

*E-635 (MO): AXION SEARCH (FERMILAB, VPI) (8)

*E-636 (PLESS): BEAM DUMP WITH 32" BUBBLE CHAMBER (BROWN, FERMILAB, INDIANA, IHEP/BEIJING, MIT, ORNL, SETON HALL, TENNESSEE, TOHOKU, TOHOKU GAKUIN) (37)

*E-640 (LOKEN): MUON SCATTERING WITH BERKELEY/PRINCETON MULTIMUON SPECTROMETER (FERMILAB, LBL, PRINCETON) (12)

*E-646 (BALTAY): BEAM DUMP WITH 15 FT. BUBBLE CHAMBER (BERKELEY, COLUMBIA, FERMILAB, HAWAII, RUTGERS, STEVENS) (27)

*E-649 (TAYLOR): NEUTRINO EXPERIMENT (LAB C) (FERMILAB, MIT, MICHIGAN STATE, NORTHERN ILLINOIS) (28)

*E-652 (SCIULLI): NEUTRINO EXPERIMENT (LAB E) (CHICAGO, COLUMBIA, FERMILAB, ROCHESTER, ROCKEFELLER) (32)

*E-653 (REAY): HADRONIC PRODUCTION OF CHARM AND BEAUTY (HYBRID EMULSION SPECTROMETER) (CARNEGIE-MELLON, DAVIS, KOBE-OSAKA COLLABORATION, NAGOYA COLLABORATION, KOREA, OKLAHOMA, OHIO STATE) (49)

*E-665 (KIRK): OPEN GEOMETRY MUON SCATTERING EXPERIMENT (CRACOW, FERMILAB, FREIBURG, HARVARD, MARYLAND, MIT, MPI/MUNICH, SAN DIEGO, WASHINGTON, WUPPERTAL, YALE) (38)

*E-672 (DZIERBA): HIGH P_T JETS AND HIGH MASS DI-MUONS (ARIZONA, CALTECH, FERMILAB, FLORIDA STATE, GEORGE MASON, ILLINOIS/CHICAGO, IHEP/SERPUKHOV, INDIANA, MARYLAND, RUTGERS) (47)

*E-683 (CORMELL): PHOTOPRODUCTION OF JETS (ARIZONA, ARGONNE, FERMILAB, LEHIGH, PENNSYLVANIA, RICE, VANDERBILT, WISCONSIN) (20)

*E-687 (CUMALAT): PHOTOPRODUCTION OF CHARM AND BEAUTY (COLORADO, FERMILAB, ILLINOIS, INFN/FRASCATI/MILANO, NORTHWESTERN, NOTRE DAME) (36)

*E-690 (KNAPP): CHARM AND BEAUTY PRODUCTION (COLUMBIA, FERMILAB, MASSACHUSETTS, MEXICO) (12)

*E-691 (NASH): CHARM PRODUCTION BY TAGGED PHOTONS (CARLETON, COLORADO, FERMILAB, NRC/CANADA, OKLAHOMA, SANTA BARBARA, TORONTO) (42)

*E-704 (YOKOSAWA): POLARIZED BEAM EXPERIMENTS (ARGONNE, SERPUKHOV, KYOTO, ANNECY, NORTHWESTERN, TRIESTE, RICE) (45)

*E-705 (COX): CHARMONIUM AND DIRECT PHOTON (ATHENS, FERMILAB, DUKE, McGILL, NORTHWESTERN, SHANDONG) (38)

*E-706 (SLATTERY): DIRECT PHOTON (FERMILAB, MSU, MINNESOTA, NORTHEASTERN, PENNSYLVANIA STATE, PITTSBURGH, ROCHESTER) (44)

*E-711 (LEVINTHAL): HADRONIC CONSTITUENT SCATTERING (CARLETON, DAVIS, FERMILAB, FLORIDA STATE, ILLINOIS/CHICAGO, MICHIGAN, OHIO STATE, ROCHESTER) (15)

E-715 (COOPER): $\Sigma\beta$-DECAY (CHICAGO, ELMHURST COLLEGE, FERMILAB, IOWA, IOWA STATE, LENINGRAD, YALE) (28)

*TEVATRON EXPERIMENTS

*T-721 (BUCHHOLZ): CP VIOLATION (FERMILAB, McGILL, ATHENS, SHANDONG, NORTHWESTERN) (33)

*E-731 (WINSTEIN): PRECISION MEASUREMENT OF $|\eta_{00}/\eta_{+-}|$ (CHICAGO, FERMILAB, PRINCETON, SACLAY) (11)

*E-733 (BROCK): NEUTRINO EXPERIMENT WITH QUAD TRIPLET BEAM (LAB C) (FERMILAB, MIT, MICHIGAN STATE, NORTHERN ILLINOIS) (21)

*E-743 (REUCROFT): CHARM PRODUCTION WITH LEBC (BRUSSELS, CERN, PARIS, DUKE, FERMILAB, KANSAS, MICHIGAN, NOTRE DAME, LPNHE/PARIS, STRASBOURG, TUFTS, VIRGINIA TECH) (38)

*E-744 (MERRITT): NEUTRINO EXPERIMENT WITH QUAD TRIPLET BEAM (LAB E) (CHICAGO, COLUMBIA, FERMILAB, ROCHESTER) (23)

*E-745 (KITAGAKI): NEUTRINO EXPERIMENT WITH HIGH RESOLUTION BUBBLE CHAMBER (ENGINEERING RUN FOR E-636) (BROWN, FERMILAB, INDIANA, IHEP, MIT, OAK RIDGE, TECHNION, TEL AVIV, TENNESSEE, TOHOKU, TOHOKU GAKUIN) (54)

*TEVATRON EXPERIMENTS

2/9/84

Appendix IV

CDF Collaborators

Argonne National Laboratory

Brandeis University

University of Chicago

Fermi National Accelerator Laboratory

INFN, Frascati (Italy)

Fukui University (Japan)

Harvard University

University of Illinois

KEK (Japan)

Lawrence Berkeley Laboratory

University of Pennsylvania

INFN, Pisa (Italy)

Purdue University

Rockefeller University

Rutgers University

Saga University (Japan)

Texas A & M University

ICRR, Tokyo (Japan)

Tsukuba University (Japan)

University of Wisconsin

Mr. CARNEY. Thank you, Dr. Lederman. Thank you for the job that you are doing at Fermilab.

I now will yield to Dr. Richter for his testimony.

STATEMENT OF DR. BURTON RICHTER, TECHNICAL DIRECTOR, STANFORD LINEAR ACCELERATOR CENTER, STANFORD, CALIF.

Dr. RICHTER. Thank you, Mr. Chairman. I ask that a written version of my remarks be submitted for the record.

Mr. CARNEY. Without objection, they will be.

Dr. RICHTER. About 1 year ago, I testified here at hearings on the authorization of this project, which is to be both a new departure in electron positron colliding beam facilities and a machine that gives new opportunities for scientists to carry out experiments at the forefront of high energy physics. Since those hearings, the construction project was started; Congress approved $32 million for the first year of construction funding for the SLC, out of a total estimated cost of $112 million.

At these hearings, I will review the status of the project, both technical and fiscal, and describe our plans for physics experiments with the completed machine.

As I just mentioned, the SLC is a new departure in accelerator technology, and before describing our progress, it might be useful to remind you of why a new departure is necessary. The old technology is that of the colliding beam storage rings, wherein beams of electrons and positrons circulate in opposite directions in a single magnetic guide field, and the same particle bunches collide with each other many times per second.

The first of these electron storage rings, the Princeton-Stanford machine, was begun in 1958, and the newest and largest of these machines, the LEP project at CERN, was begun in 1983. If all goes well, the LEP facility at CERN will run in 1988 or early 1989, at an energy of 100 GeV in the center of mass, the same energy as that of the SLC.

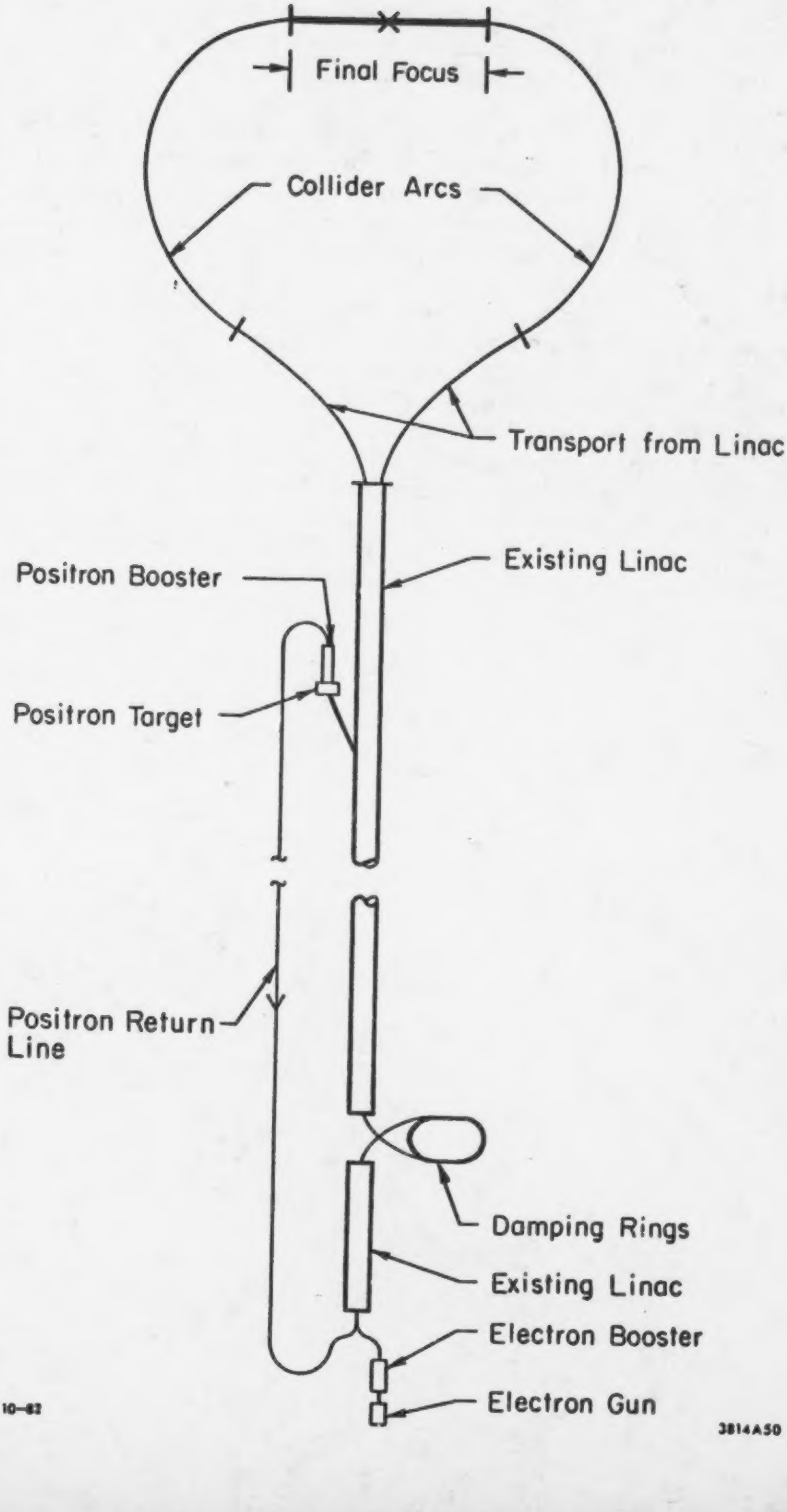
In the 25 years since the start of the first of these machines to the start of the LEP project, the radii of these machines have grown 5,000-fold, while the energies have gone up 100-fold. In these 25 years, the storage ring technique has become a mature technology, and in that mature technology, the unit cost of components that make up a machine are well known, and it is possible to write scaling laws that predict with quite high accuracy the cost of a new facility, even before the detailed design of that facility has been made.

This was done for the LEP project, for example, and the scaling laws predicted the cost of the machine to within 10 percent of the estimate arrived at after detailed design was complete. Those scaling laws indicate, as mentioned by Dr. Trivelpiece earlier, that the cost of electron storage rings goes up as the square of the energy. The LEP project is estimated to cost 900 million fiscal year 1982 Swiss francs, about $500 million. A machine of 10 times the energy will cost 100 times as much, $50 billion. It would also be 100 times the size. LEP has a circumference of 16 miles. A machine of 10 times the energy, built the same way, would have a circumference of 1,600 miles, which dwarfs even the SSC.

We concluded at SLAC in 1977 that the cost-scaling law would probably block the extension of this particular storage ring technology, and we began to search for an alternative that would allow this kind of physics to be done at higher energy when such high energies were needed. The SLC is the result of our research. It is a variant of a class of machines called linear colliders that have scaling laws where costs increase much less rapidly with energy than those of storage rings.

A sketch of the SLC project is shown in the first transparency. The SLC consists of an upgrade of the SLAC linear accelerator to increase its energy to 50 GeV. In the linac a bunch of electrons and a bunch of positrons are both boosted to high energy, come to the end of the linac, swing into the two arcs on opposite sides, and finally reach the collision point where the interactions happen. The tunnels are 2.8 kilometers in total length, and in those tunnels small magnets guide the particles through the arc and bring them to the special final focus region.

Fig. 1


Final Focus
Collider Arcs
Transport from Linac
Existing Linac
Positron Booster
Positron Target
Positron Return Line
Damping Rings
Existing Linac
Electron Booster
Electron Gun
10-82
3814A50

The third bunch shown in that transparency is snatched from the linac at about the two-thirds point and is used to reproduce the positions.

We also require for the project a vastly more powerful electron injector than is normally used in the linac, special modifications to the first section of the linac, and damping rings at the end of the first 100 meters of the machine to shrink the beam to the necessary small size.

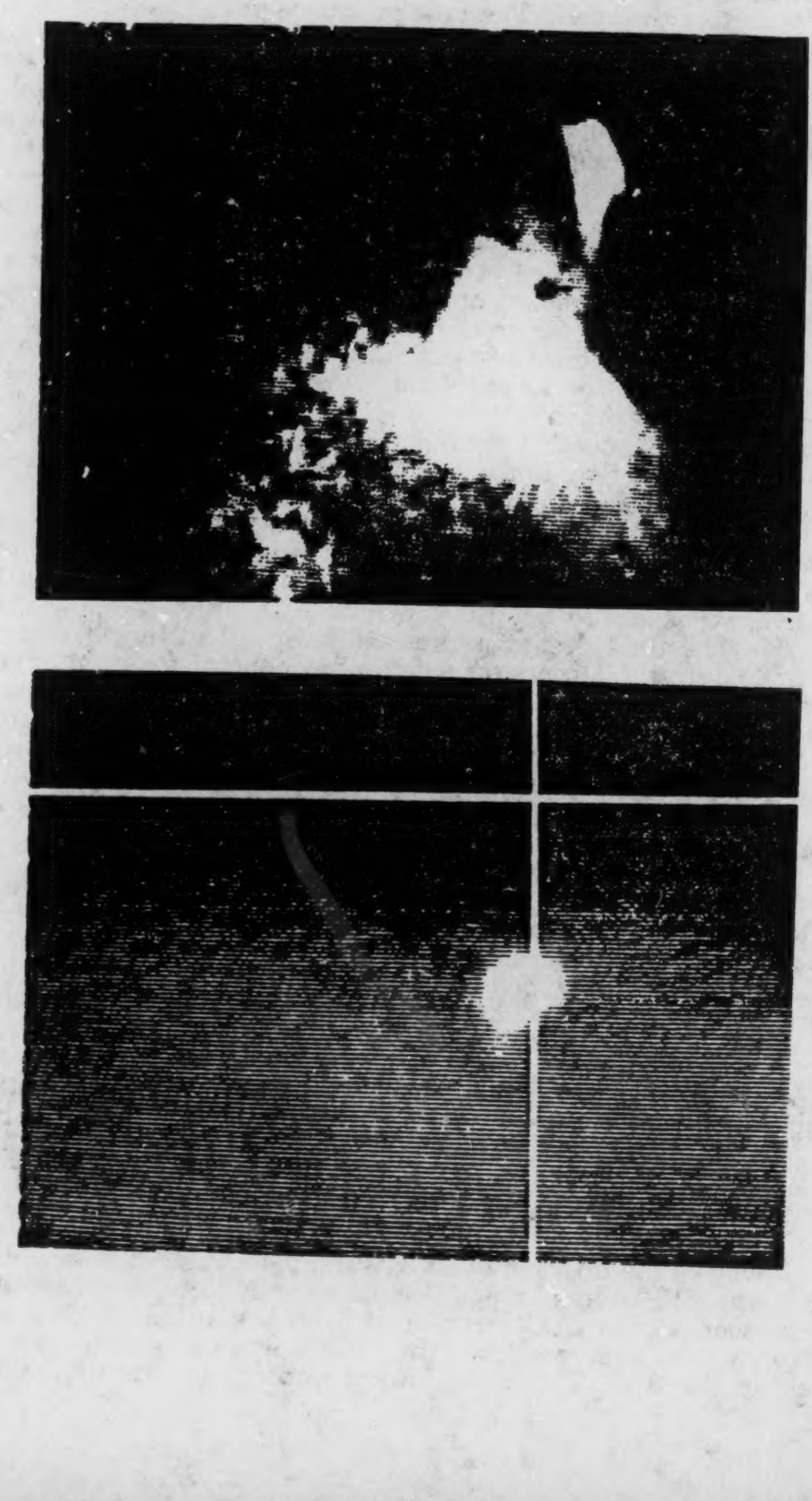
During the past few years, we have conducted an intense R&D program on some of the more advanced components of the SLC. The program has concentrated on developing a new electron injector, developing a damping ring to shrink the bunches down, and the production of new high-powered klystron required for the energy upgrade.

The electron injector has been under development for the past 2 years, and it is designed to produce bunches of electrons a factor of 100 more intense than the bunches produced by the standard injector used for normal operations of the machine. The device has been successfully tested and has bettered all of its design specifications.

The prototype damping ring, together with the necessary extraction equipment to bring a beam from the linac to it and to return beams from it to the linac has been under test for the last 6 months. It works quite well, and its effect on the beam properties is dramatically illustrated in the next transparency.

Fig. 2

SLC beam after 1 km of accelerator: a) without passing through damping ring;
b) passing through damping ring.



The upper picture shows a beam directly from the new gun, accelerated to an energy of about 9 GeV—that is about a kilometer from the gun. You can see the little holes in the bottom of the upper picture that are calibration marks. Each one is three-tenths of a millimeter in diameter. Space-charge forces right at the injector badly distort the beam. The lower picture shows the same beam after it has been injected into the damping ring and extracted from it and reinjected into the linac. The damping ring has shrunk the size of the beam, and the reinjection occurs at an energy of 1 GeV, where these space-change forces are much weaker, and that entire beam spot will fit through one of the holes in the screen. This illustrates a very important milestone in the R&D program.

The development of the new klystrons required for the energy upgrade has proceeded somewhat more slowly than we had hoped. We have recently succeeded in producing a successful prototype of the 50-megawatt klystron we need, and we are now in the process of building and testing six more preproduction prototypes. One of these has been through all tests and has passed with flying colors. The next two are in the midst of their test, and the last three are in various stages of construction.

In October 1983, the first working day of fiscal year 1984, we received our construction funds and signed a contract for the construction of the 3 kilometers of tunnel required for the collider arcs. Tunneling is well underway, and the construction schedule is proceeding faster than our engineers had originally expected. The design of the experimental hall at the collision point is nearly final, and we expect to let this contract in the first part of fiscal year 1985. The final design is proceeding on all technical components of the project. Orders for steel and conductor for most of the magnets have been placed, and so forth. Our spending program at the moment is right on track, and the pace of the project is limited by availability of funds. We have completed a thorough reestimate of the total cost of the project, and as usual in such reestimates, some components have increased in cost while others have decreased. The budget remains in good shape.

During fiscal year 1985, the Department of Energy's budget request for the SLC project is $60.5 million. With these funds, we will construct the Experimental Hall and a large fraction of the technical components for the facility. We expect to begin installation of magnets in the tunnel before the end of fiscal year 1985. The project will still be paced by the availability of funding and the $60.5 million is required to keep to the 3-year construction schedule that we have planned.

The SLC is expected to begin operations toward the end of calendar 1986. The much larger and most costly European project, LEP, is expected to begin operation at the end of calendar 1988. The initial design parameters in energy and in intensity for both the SLC and LEP are about the same.

We have planned our physics program in two phases. The first phase involves the upgrade of an existing detector that is now running at the PEP storage ring. This detector is to be ready to take data as soon as the SLC turns on. In the beginning of 1986, this detector will be removed from the PEP storage ring and start its travels to the SLC. The collaboration working on the upgrade is composed of physicists from eight U.S. institutions and is still expanding.

The second phase of the experimental physics program involves the construction of a new detector that is optimized for work in the SLC energy region. The upgraded detector from PEP will carry out some very interesting early physics, but it is not possible to increase its capabilities at reasonable cost to do justice to the full span of physics which we expect to be able to study with the SLC. The collaboration working on the new detector includes physicists from 12 U.S. institutions and from 3 foreign laboratories. There are 65 Ph.D. physicists committed to this project at the present moment, and this group is also still expanding. This new apparatus, we hope, will be ready to make its contribution to our experimental capabilities in fiscal year 1989, although its construction will be paced by the availability of equipment funding.

The SLC has certain unique capabilities for research that will not be duplicated elsewhere. It will have polarized beams that will allow unique tests of our theory of the weak interaction and, in addition, the extremely small size of the SLC collision region will allow lifetime measurements of unstable particles that cannot be done elsewhere. These unique features, together with an energy and intensity that match those available on LEP, assure us that the new detector and the physics program will continue in the forefront of research for a long time.

Thank you.

[The prepared statement of Dr. Richter follows:]

STATEMENT BEFORE THE SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS

House Committee on Science and Technology

Burton Richter
February 22, 1984

INTRODUCTION

I welcome the opportunity to testify again before this Committee on the status of the SLAC Linear Collider (SLC) project. About one year ago I testified here at your hearings on the authorization of this project which is to be both a new departure in technology for electron-positron colliding-beam facilities and a machine that gives new opportunities for scientists to carry out experiments at the forefront of High Energy Physics. Since those hearings, the Congress has authorized the project and approved $32 M of funds for the first year of construction out of a total estimated cost of $112 M. At these hearings I will review the status of the project, both technical and fiscal, and describe our plans for physics experiments with the completed machine.

THE MACHINE

As I mentioned before, the SLC is a new departure in accelerator technology. Before describing our progress, it might be useful to remind you why a new departure is necessary. The "old" technology is that of the colliding-beam storage rings wherein beams of electrons and positrons circulate in opposite directions in a single magnetic guide field and the same particle bunches collide with each other many times per second. The first of these electron storage rings, the Princeton-Stanford machine was begun in 1958. The newest and largest of these machines, the LEP project at CERN was begun two years ago and if all goes well, that facility will be operating in late 1988 or early 1989 at an energy of 100 GeV in the center-of-mass, the same as the design energy of the SLC.

In the 25 years from the start of construction of the Princeton-Stanford machine to the start of the LEP project, the radii of these machines have grown 5000-fold while the energies of the machines have grown 100-fold. In these 25 years the storage ring technique has become a mature technology. The unit cost of the components that make up a machine are known with relatively high accuracy, and it is possible to write scaling laws that quite accurately predict the cost of a new facility even before the detailed design of that facility has been made. This was done for the LEP project and the scaling laws predicted the cost of the machine to within 10% of the estimate arrived at after detailed design was complete. These scaling laws indicate that the cost of a storage ring grows as the square of its energy.

The LEP project is estimated to cost $900 M Swiss Francs (1982 costs) plus staff costs. A machine of ten times the energy of LEP, which might very well be an appropriate step to take sometime in the next decade, would cost one hundred times as much. We at SLAC concluded in 1977 that the cost scaling law would probably block the extension of the storage ring technology to machines beyond the size of LEP and we began then the search for an alternative that would allow this kind of physics to be continued to higher energy if such expansion were warranted.

The SLC is the result of our research. It is a variant of a class of machines called linear colliders which have scaling laws such that their costs increase much less rapidly with energy than those of storage rings. A sketch of the SLC project is shown in Figure 1. In the SLC, a single bunch of electrons and a single bunch of positrons are simultaneously accelerated to high energy in an upgraded version of the existing SLAC two-mile linear accelerator (linac). At the end of the linac, the two bunches are separated and each enters its own branch of a tunnel of total length 2.8 km. In the tunnel, small magnets guide the particles through the opposite arcs and bring them to a special region containing the final focus equipment. The final focus system reduces the size of each bunch to a diameter of about 2.5 microns and makes the bunches collide at the center of an underground vault where the experiments are to be performed. Also required for the project are a vastly more powerful electron injector than is normally used on the linac, special modifications to the first 100 meters of the machine to allow these intense bunches to be accelerated, a pair of small storage rings to shrink the size of the electron and positron bunches and to reinject them into the linac, and various components required for the production of positrons.

THE R&D PROGRAM

During the past few years we have conducted an intense R&D program on some of the more advanced components of the SLC. This program has concentrated on developing the new electron injector required to produce the very intense bunches; a damping ring required to shrink the size of the bunches produced by this high powered injector down to the transverse dimensions required for the SLC; and on the production of a new high-power klystron required to increase the energy of our existing linac.

The electron injector has been under development for the past two years. It is designed to produce bunches of electrons a factor of 100 more intense than the bunches produced by the standard injector used for normal operations of the linac. This device has been successfully tested and has bettered all of its design specifications.

The prototype damping ring, together with the necessary extraction equipment to bring a beam from the first section of the linac into the damping ring and the necessary reinjection equipment to transport the beam from the damping ring back into the linac, has been under test for the last six months. It works quite well and its effect on the beam properties in the linac is dramatically illustrated by the two pictures in Figure 2. The first shows a high energy beam coming directly from the new injector. This beam is badly distorted by space-charge effects that occur at the injector when the beam has an extremely low energy. The second picture shows the effect of running the same intensity bunch through the damping ring before reinjection into the linac. The damping ring has shrunk the size of the beam to the necessary small transverse dimensions required for proper operation of the SLC. These pictures were taken about a month ago and illustrate an important milestone in the project.

The development of the new klystron required for the energy upgrade has proceeded somewhat more slowly than we had hoped. Last November, we succeeded in producing the first of our new klystrons capable of producing a pulse of 50 MW peak power which met all of the power and stability criteria required for the energy upgrade. We are now in the process of producing a series of six production prototype tubes, and if these tubes meet our specifications, we are confident that we will have a successful klystron. The first of the production prototypes has been through the full test program and meets specifications. The next two are in the midst of their tests and are doing well, while the last three are in the last phases of manufacture. Should a problem develop with this tube, we have a fall-back position which is more complex and uses our existing 36-MW peak power tubes.

THE CONSTRUCTION PROGRAM

On October 3, 1983, the first working day of fiscal year 1984, we received our construction funding and signed the contract for the construction of the three kilometers of tunnel required for the collider arcs. Gates and Fox Inc., the low bidder, gave us both a favorable price and a construction schedule faster than our engineers had expected. They are hard at work and the tunnel is proceeding well.

The design of the Experimental Hall at the collision point is nearly final and we expect to let the contract for this last major bit of conventional construction in fiscal year 1985. The construction funds available in fiscal year 1984 are insufficient for us to begin this project before then.

Final design is proceeding on all technical components for the project and the orders for steel and conductor for most of the magnets have been placed. Four months into the fiscal year, our spending program is right on track, and the pace of the project is being limited by the availability of funds. We have just completed a thorough re-estimate of the total cost of the project and, as usual in such estimates, some components have increased in cost while others have decreased. The budget seems in good shape.

During fiscal year 1985, the Department of Energy's budget request for the SLC project is $60.5 M. With these funds, we will construct the Experimental Hall and a large fraction of the technical components for the facility. We expect to begin installation of magnets in the tunnel before the end of fiscal year 1985. The project will still be paced by the availability of funding and the $60.5 M is required to keep to the three year construction schedule that we have planned.

PHYSICS PROGRAM

The SLC is expected to begin operations toward the end of Calendar 1986. The much larger and more costly European project, LEP, is expected to begin operation at the end of Calendar 1988. The initial design parameters in energy and intensity for both the SLC and LEP are about the same. We have planned our experimental physics program in two phases. The first phase involves the upgrade of an existing detector that is now running at the PEP Storage Ring. This detector is to be ready to take data as soon as the SLC turns on. The upgrade is proceeding rapidly and most of the new components will be installed and tested at the PEP Storage Ring during Calendar 1985. At the beginning of 1986, this detector will be removed from the PEP Storage Ring and start its travels to the SLC. The collaboration working on the upgrade is composed of physicists from eight U.S. institutions and is still expanding. There are 54 Ph.D. physicists now working on this project and the group expects to add a considerable number of post-doctoral research associates and students during the next year or two.

The second phase of the experimental physics program involves the construction of a new detector that is optimized to work in the SLC energy region. The upgraded detector moved from PEP will carry out some very interesting early physics but it is not possible to increase its capabilities at reasonable cost to do justice to the full span of physics which we expect to be able to study with the SLC. The collaboration working on the new detector includes physicists from 12 U.S. institutions and 3 foreign laboratories. There are 65 Ph.D. physicists committed to this project at the present moment and this group is also still expanding. The new apparatus should be ready to make its contribution to our experimental capabilities in fiscal year 1989.

The SLC has certain unique capabilities for research that will not be duplicated elsewhere. It will have polarized beams that will allow unique tests of our theory of the weak interaction, and, in addition, the extremely small size of the SLC collision region will allow lifetime measurements of unstable particles that cannot be done elsewhere. These unique features, together with an energy and intensity that match those available on LEP, assure us that the new detector will contribute forefront physics research for a long time.

Fig. 1

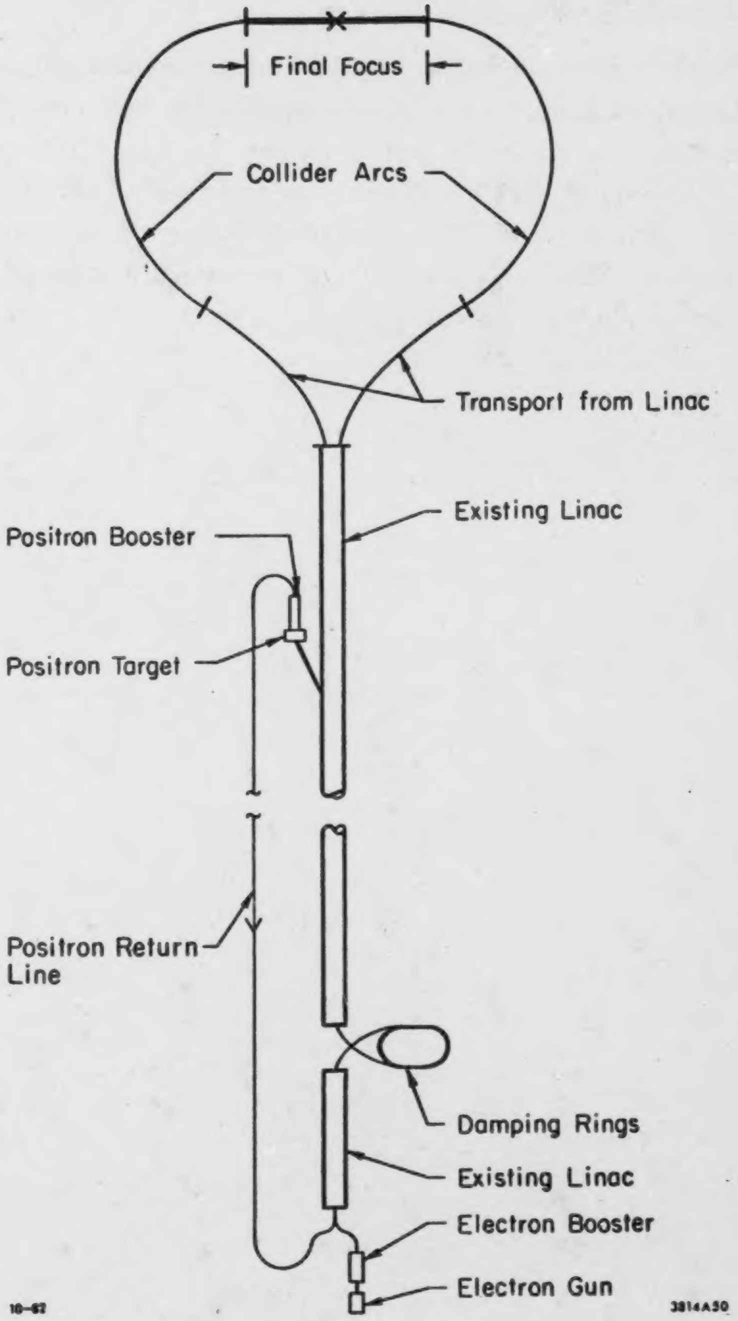

Final Focus
Collider Arcs
Transport from Linac
Existing Linac
Positron Booster
Positron Target
Positron Return Line
Damping Rings
Existing Linac
Electron Booster
Electron Gun
10-82
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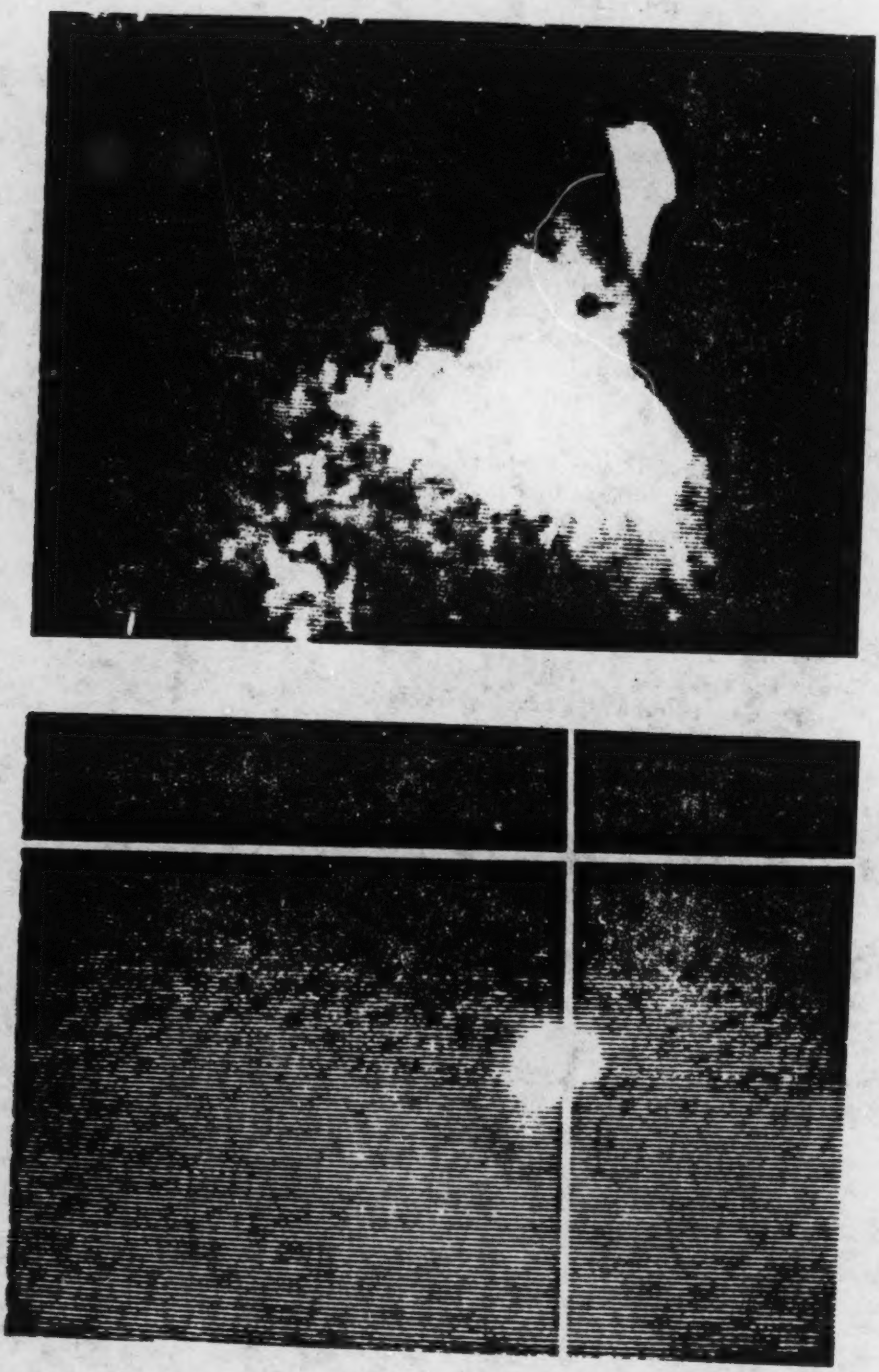
Fig. 2

SLC beam after 1 km of accelerator: a) without passing through damping ring;
b) passing through damping ring.



CURRICULUM VITAE

Burton Richter – Paul Pigott Professor in the Physical Sciences;
Technical Director, Stanford Linear Accelerator Center,
Stanford University

Born – March 22, 1931

Education

B.S. – Massachusetts Institute of Technology – June 1952
Ph.D. – Massachusetts Institute of Technology – September 1956

Employment

Research Associate, High Energy Physics Laboratory, Stanford University, 1956–1960
Assistant Professor, Physics Department, Stanford University, 1960–1963
Associate Professor, Stanford Linear Accelerator Center, Stanford University, 1963–1967
Professor, Stanford Linear Accelerator Center, Stanford University, 1967–
Technical Director, Stanford Linear Accelerator Center, Stanford University, 1982–

Honors & Awards

Loeb Lecture, Harvard University, 1974
DeShalit Lecturer, Weizmann Institute, 1975
E. O. Lawrence Medal (U.S. Department of Energy), 1976
Nobel Prize in Physics, 1976
National Academy of Sciences, 1977

Professional Societies

American Physical Society (Fellow)
American Association for the Advancement of Science (Fellow)
European Physical Society

Present Committees, Consultantships & Directorships

General Motors Science Advisory Committee
Mitre Corporation – Jason Group
Advisory Committee – Max Planck Institute, Munich, Germany
Accelerator Advisory Committee, CERN, Geneva, Switzerland
Director, Middlefield Capital Corporation
Director, Teknowledge, Inc.

February 1984

Mr. CARNEY. Thank you very much, Doctor.

If I may, I'd like to address my first couple of questions to you, Dr. Richter.

One, with LEP's schedule and your schedule for completion, there is a 2-year gap. Would there be a profound impact in your program if we were to stretch out your construction requirement in fiscal year 1985 for an additional year? That's a marshmallow question for someone like you.

Dr. RICHTER. Well, there's one impact on all of us that you mentioned earlier; delays in construction projects that run their costs up and the Federal budget can't afford much increase in such costs. Also, we have an opportunity to get the U.S. physics program back into forefront research. The two tools described here, the Tevitron-I program at Fermi Lab and the SLC program, will be the U.S. forefront machines until the SSC is constructed; and I think the physics community would certainly be very disappointed at a delay in a chance to get at these forefront facilities and start finding out the answers to some of the questions they were designed to investigate.

Mr. CARNEY. I think that would apply to all facilities, both the cost of stretching our programs and the morale factor involved in the users of those programs; and I think too, we have to recognize having the user physics community active, here within the boundaries of the United States as opposed to the builder physics community—we have to have a healthy balance of both. And I think I concur.

I have a little bit of concern about your facility and that is with its power allocation from WAPA. What type of impact would that have?

Dr. RICHTER. With the new facility, our power consumption is going to increase by something on the order of 15 or 20 megawatts. At present we have a WAPA allocation, public power, of 25 megawatts of firm power; and, through WAPA's arcane system, 12½ megawatts of withdrawable and 6 megawatts of diversity. We don't know what is going to happen to that power allocation, and as time goes on it makes less and less difference what happens. The Federal Government's policy is to raise the costs of public power and make it more competitive with private power, and WAPA's rates are going up much, much faster than inflation. They're projected to triple over the next 3 years, and then they'll still be a bit cheaper than private power; but the ratio won't be anything like it is now.

Our operating budget will go up because of the need for new power, and it will go up because of the WAPA rate increase.

Mr. CARNEY. Will there be available electricity?

Dr. RICHTER. There is available electricity. There is a surplus of electricity in the Pacific Northwest, and negotiations are going on in the various branches of the Federal Government involved in distributing this power to try to get some of that Pacific Northwest power down into California. There is plenty of power; the question is always, what will it cost?

Mr. CARNEY. Thank you

Dr. Tigner, if I may, I have recollections of hearings prior to this particular hearing dealing with various machines and devices, and we seem to, as a Congress, receive mixed signals. I'm not so sure that's happening now, but I'm somewhat concerned. You made a presentation for SSC, an overview of what you might think the facility would look like, what you're aiming at as far as its energy requirements, what its function would be; and yet, we've had signals saying that we should go along more aggressively. You were in the audience when Dr. Trivelpiece made his presentation. I have this mixed signal coming down that perhaps we might not go forward with the SSC. What is Congress to do? We're dealing with the largest endeavor in our nation's history. Obviously, to any witness in the audience today, there is some skepticism from Members of Congress as to whether we should go forward with the project, and some others believe we should do a joint venture with other nations. But we're not getting clear signals. Could you try to give me your opinion on whether we have ample funding to continue aggressively the SSC program?

Dr. TIGNER. Thank you. I certainly agree with Dr. Trivelpiece that the scientists who are working on the project would feel as if we're being held back somewhat. On the other hand, we are working very hard. I think what you're seeing here on this reference design study is a very hard attempt by all those in the U.S. energy physics community to pull ourselves together, to understand what it is we really need to do right now, what we can do right now, and what the best way to do it is. And I expect to see these issues which you mentioned, resolved very quickly. I think that's what we're really trying very hard to do now, and I'm confident that the DOE is listening to what we're doing. We're working closely with them.

Mr. CARNEY. Do you have the resources to do it?

Dr. TIGNER. To do the phase of the activity which we're in right now, we have ample resources. We will not have ample resources—this level of resources which are being provided now, of course, will not be adequate when we really see exactly how we should—when we have a plan, for actually applying the resources to the job. However, I'm confident that the DOE will be listening to that and that they'll be responsive to our well-articulated requests which will be coming forth rather shortly.

Mr. CARNEY. Could you tell me, for the $39.5 million, what you are doing in phase 0?

Dr. TIGNER. I think I should defer that to Dr. Trivelpiece. I'm working on a small part of the intellectual study which is trying to do the planning, not on the disposition of the funds.

Mr. CARNEY. You're not in a position, then, to say what is going on in the high energy physics community with that $39.5 million?

Dr. TIGNER. I can certainly tell you what I know about my perspective. That's not under the purview of my management responsibilities, as you know; if you wish, however, I can recount for you the kinds of activities which we are doing.

Mr. CARNEY. The SSC Reference Designs Study Organization has you down as "leader."

Dr. TIGNER. Yes; the reference study design activity; is a 3-month activity which will end at the end of April and which will provide this report which I described to you.

Mr. **Carney**. Is there anything else going on besides the reference study design?

Dr. **Tigner**. Yes, sir, there certainly are R&D activities going on at the various laboratories which are being managed by the DOE.

Mr. **Carney**. The magnet R&D, for instance, at Fermi, at Brookhaven, that type of thing, is being done with the money that was put through reprogramming?

Dr. **Tigner**. Yes.

Mr. **Carney**. But what is very important are the reference designs if we're going to go forward. That's what will be ultimately decided in August as the timeframe that we have. That will make the decision as to whether we go forward with an SSC, is that not correct?

Dr. **Tigner**. As I understand the meaning of the August decision on the DOE directly is that this will represent a decision to go forward robustly with the R&D program, which will lead to a firm proposal and cost estimate and construction at the end of this 3-year phase I R&D period.

Mr. **Carney**. Does the phase I R&D program still cost us the same as anticipated last year, in October—$150 million?

Dr. **Tigner**. We don't have a better estimate now, but I must say that one of the things that we're doing right now is studying very carefully exactly what the scope of that should be.

Mr. **Carney**. May I assume then, perhaps the phase zero $39.5 million will not be part of the phase I effort, and that we were specifically speaking of a phase I effort back in October 1983?

Dr. **Tigner**. Well, this phase I/phase 0 business is a bit complicated. It certainly is true that many of the actual R&D activities that are going on now will make a direct contribution to the things which we're thinking of in phase I. So in that sense they are included in it.

Mr. **Carney**. That would be magnet R&D?

Dr. **Tigner**. Yes.

Mr. **Carney**. Ongoing types of programs.

With this budget of $20 million, which looks to me would be in phase I only from the standpoint that it becomes available on October 1, decisions will have been made prior to that if we're following the SSC proposed calendar. Will $20 million be enough in fiscal year 1985 if the decision to go forward with the project is rendered?

Dr. **Tigner**. Well, I'm not terribly happy with it. As I said, we are trying very hard now to make a convincing and very detailed argument about exactly what is required in order to go forward and we are very hopeful that we will be able to convince the DOE, in fact, to support a somewhat broadened scope for these activities.

Mr. **Carney**. Well, I must admit I am a very strong supporter of the necessity of going forward with the SSC, but I've become confused by the moment. And again, I think that we're becoming recipients of very unclear signals. We're talking about timeframes and money tables; now, I begin to listen to my colleagues about the doubt of the commitment of this country to go forward with a program of great expense. What decisions do we make? Just wait another year, spend another $20 million, have no direction? HEPAP was quick to determine what they wanted to do in 1983. Now they're very quick to say, we don't know what is going on. You know, it leaves us confused; and I think it's going to be not to our detriment. We might be able to balance the budget because they won't come out with a project of this nature, and that's going to be to the detriment of high energy physics in the United States. We have to get our act together. We made a decision.

I'll ask you the question. If not SSC, then what?

Dr. TIGNER. Well, that's a very good question. I think what is important to realize is that the need for the scientific community that works in this area, the area of fundamental high energy particle physics, is to get into new—to get past new energy frontiers. The SSC appears to us—and it still appears to us—to be the most practical means for doing that at this time. If it should turn out for some reason or other which is unanticipated now that that does not work out, we will find a way to get past this energy frontier. That's what we have to do; that's what our science is all about.

Mr. CARNEY. I agree. You came before this committee, you made a presentation, this committee concurred with you; and I might say I went down scrapping and scratching on that decision. But nonetheless your wisdom prevailed, and I agreed with you, and we said, let's move forward with the SSC. That was October; we are now in February, and now you're saying to this committee, we need a few more bucks to make sure that the SSC is the right thing. It makes it extremely difficult for supporters of your program to continue to vacillate back and forth. And what you're saying, if I may—and I don't mean to put words in your mouth—are you saying that what we want to do is take a closer look at SSC, get some type of design criteria, cost criteria that you can go back to DOE and to Congress and say, we're ready to go ahead aggressively?

Dr. TIGNER. The latter, yes. I don't think we have—I'm speaking now as a member of the community— we don't have any doubts about what we want to go ahead with. Perhaps between you and us, we can convince the DOE to go ahead:

Mr. CARNEY. What you're saying, then, is that perhaps the $20 million is not enough?

Dr. TIGNER. All right, if you want me to say that, it certainly is a true statement.

[General laughter.]

Mr. CARNEY. I don't want you to say anything that's not entirely accurate and something that you want to say from your heart.

Dr. TIGNER. It's an accurate and correct statement.

Mr. CARNEY. Thank you.

I have no further questions for this panel. Mr. Chairman, do you have any questions of the panelists?

Mr. FUQUA. Yes; for Dr. Lederman and Dr. Richter, right now in the budget we're providing, I guess, utilization at about 55 percent; I assume SLAC is likewise affected by that. Is that correct?

Dr. RICHTER. We have two different kinds of utilization. We have our storage rating program and our fixed target program. The storage rating program will be running at 55 to 60 percent in fiscal year 1985; the fixed target program will be running at a rate much less than that, about 15 to 20 percent.

Mr. FUQUA. Well, are we appropriating too much money for capital improvement and so forth, and not enough for operating time?

Dr. **Richter**. That's a tough question, because after all we want both operating time and capital improvement money, both.

Mr. **Fuqua**. Maybe you agree with the priorities.

Dr. **Richter**. If I had to say the total amount of money was fixed, I would say the priorities have been reasonably chosen. If I had my druthers I'd like to see a little bit more operating money; of course, at no cost to the capital improvement project.

Mr. **Fuqua**. And by the same token, if you had antiquated equipment and instruments and so forth, you can't do the work if you're running at 100 percent.

Dr. **Richter**. That's a very serious problem——

Mr. **Fuqua**. The chicken and the egg situation.

Dr. **Richter**. It's a serious problem; it's a problem that HEPAP looked at at its last meeting on February 6 and 7. It's very clear that we have a shortage of a category of funds called equipment money, and it's equipment money that builds all these detectors; and we're having to make some very tough priority choices within our own lab, and between laboratories, too.

Mr. **Fuqua**. Dr. Lederman, maybe you wish to comment on that?

Dr. **Lederman**. That's a good question. I remember when I first considered the crazy idea of becoming a lab director I went down to Washington and talked to a lot of people about prospects, and I was told by several officials in OMB and DOE at that time that Fermi Lab, as a place, would rather build a machine than use it. And I was stunned by that, and looked into it. Well, here we are with the best accelerator on the planet in 1984, and it'll get more powerful. I'm terrified that we'll not be able to operate it with the kind of exuberance and zest and style that it deserves, considering the enormous investment in capital, both financial and human.

My considered judgment—and I know this sounds like a broken record, that a laboratory director must always say—is that we need another 5 percent. It's a terrible comment, and I'm torn because the high energy budget for 1985, the President's budget, is a fantastic demonstration of confidence in this field by the President. And how can you complain about it? But as a lab director, seeing the scientific opportunities that we have and knowing that if I'm constrained by the 1985 budget and, as Burt said, especially the capital equipment budget, I know that some beautiful opportunities for doing science with this machine will be lost. So we do have this crisis of utilization and, as usual, there's an enormous leverage factor. A 5-percent increase at Fermi Lab will give us a 25-percent increase in utilization; it'll get us up to 80 percent, and that's a good thing to do.

Mr. **Carney**. Mr. Chairman, will you yield on that?

Mr. **Fuqua**. Certainly.

Mr. **Carney**. Pursuing the chairman's questions, what effect does 55 percent utilization of the laboratory have on the community? Are they utilizing other labs outside the United States to a greater extent and presenting to the scientific community better opportunities?

Dr. **Lederman**. Well, I think it's certainly true that more of the U.S. community is working abroad now than has ever been in the past—as somebody who spent many years working at CERN—and I think this is, in general, a good thing. But at some point you have to remember that these users are citizens of their own campus and it's already a hard job to be a professor in a university, and that's where the greatest strength comes from in our scientific enterprise, the professors at the universities. For them to go abroad is a hard thing, and it ties in with your other question about international collaboration and if not SSC, what then? Clearly that's a relevant comment.

At Fermi Lab we have about a thousand users, professors and graduate students, who have signed up for the program. My guess is that about 150 of them will see their research delayed considerably because of this gap between 55 percent and 80 percent.

Mr. **Fuqua**. Are there any bureaucratic obstacles that stand in the way of more efficient management of the labs? Do the lab directors have enough independence that they can eliminate some of these obstacles? Is it an overhead problem that's causing some of it?

Dr. **Lederman**. That's a very good question. There has been, for many years, an increasing burden of bureaucratic exercises that we have to go through. We have been complaining about this to the Department of Energy.

I think part of the trouble is that the Program Office, the office of the Department of Energy that is concerned with our mission knows our mission, and we can communicate very will with them, but there is a vast part of the bureaucratic structure that really doesn't get concerned with our mission; they're concerned with other things like our safety, security, how many tires will we need 10 years from now, and this paperwork has just mushroomed. I think there's an awareness on the part of—at a high level in the Department of Energy that this process has to be managed. It seems to be an extremely difficult thing to manage, and so we have this enormous paperwork burden. A lot of it is content-free; a lot of it has some rationale, perhaps, but when you take it en masse it's a serious problem for the laboratory. I think the notion of a GOCO, a Government-owned, contractor-operated laboratory is a beautiful and simple notion if the Government would preserve its right for oversight—we need that—but let the contractor manage his laboratory and fire him if he mismanages. I think Congress is not innocent of this, too; it would be beautiful if we could look at our funding profile over 2 years rather than 1 year for planning.

It would also be useful if we didn't have this rigid demarcation between different colors of money—capital equipment, plant, operation—give us some flexibility and we would be helped. The Department of Energy people whom we cry to about these burdens blame it on Congress. Somehow I think it would be nice to improve things.

Mr. **Fuqua**. I might add, we're looking at a 3-year authorization bill this year, so that may give some relief.

Is there any indication that the top echelon of DOE is doing any serious consideration, maybe reorganizing themselves or maybe managerial improvement to eliminate some of the burdensome things that in the end cost more money?

Dr. **Lederman**. Well, I think there is an awareness. We've had, in fact, directors' meetings at which the Secretary has listened, and also other high officials. I'm an incurable optimist; I think somehow things will get better.

Mr. **Fuqua**. Dr. Richter, maybe you would care to comment?

Dr. **Richter**. I haven't had Leon's experience at being a director; I'm not one yet——

Mr. **Fuqua**. But you're about to get that experience.

Dr. **Richter** [continuing]. But I'm about to see what life is like in that position. I've been a working man most of my time, and the laboratory director has shielded me in that part of my career from all of this sort of thing that Leon is talking about.

There clearly is too much regulation and too much detail from Washington. I can see that even at my level. There ought to be less of it. I hear from the lab directors who have had meetings with the Secretary of Energy that he's trying to do something about this problem; whether the Secretary will succeed or not, I don't really know. It's a very hard thing to do.

One of the problems that Leon raised is one where, I think, Congress can do more than the Department can. And that is the rigid categorization of funding which decreases our flexibility to do the sorts of things which are in the best interests of the program. Right now we have a rigid pot called equipment and a rigid pot called operating, and the operating is actually broken down into a bunch of categories which don't match precisely what we really do. And the flexibility to move funds from one category to another is really extremely limited; and that, I think, hurts the program. Within a fixed budget we could do better if we could move resources between those categories.

Mr. **Fuqua**. Thank you.

Mr. **Carney**. Well, that's all the questions we have for this panel. I would like to say, Mr. Chairman, in your absence there was a unanimous consent made among the members present to remove you permanently as chairman and install me as chairman, and it failed, one-zip. I voted for you; I yield back your chair. [General laughter.]

Mr. **Fuqua**. Thank you gentlemen, very much, for being here.

The next panel has Dr. Schiffer, Chairman of the DOE/NSF Nuclear Science Advisory Committee with the Argonne Laboratory; Prof. Sam Austin, Cyclotron Laboratory, Michigan State; Prof. Harry Holmgren, president of the Southeastern University Research Association, department of physics and astronomy from the University of Maryland; and Prof. James S. McCarthy, vice president of Southeastern University Research Association, Department of Physics, University of Virginia. Gentlemen, we're very delighted to have you here today and if you have prepared statements that you wish to submit for the record, we will do that; and if you wish to summarize, that would certainly be agreeable.

Dr. Schiffer?

Dr. **Schiffer**. Mr. Chairman, I would like to ask that the statement be part of the record.

Mr. **Fuqua**. It will, for all the members of the panel.

Dr. **Schiffer**. And I'll just outline what's in them.

STATEMENT OF DR. JOHN P. SCHIFFER, CHAIRMAN, DOE/NSF NUCLEAR SCIENCE ADVISORY COMMITTEE, ARGONNE NATIONAL LABORATORY

Dr. SCHIFFER. I appreciate this opportunity to talk to you about nuclear physics. I am currently Chairman of the DOE/NSF Nuclear Science Advisory Committee, and Prof. Herman Feshbach, who was chairman of this committee in the past, has testified several times in front of you before.

During 1983 our committee was asked to prepare a long range plan for nuclear science, an activity in which we involved wider membership of our community, including the division of nuclear physics of the American Physical Society whose current chairman, Dr. Evans Hayward, is here in the audience today.

Nuclear physics is a sister field to high energy physics, and it's appropriate that they be covered in the same hearings. Nuclear physics is concerned with the properties of atomic nuclei, which is the substance of 99.9 percent of all matter. Many of the processes that we are concerned with are nuclear in origin; as you know, even the sun is a giant nuclear fusion reactor, and this year the 1983 Nobel Prize went to Prof. William Fowler of the California Institute of Technology for his pioneering work in understanding nuclear reactions inside stars.

It's been 75 years since nuclei have been discovered. Enormous advances have been made in our understanding of what nuclei are made of, what nuclear matter consists of, and how to think about it. Much of this advance has come from the U.S. program in nuclear research. But there are enormous areas of which we are still ignorant, where we need to advance our knowledge: nuclear structure, dynamics, the basic nuclear interactions. Nuclei and nuclear processes and techniques of nuclear physics have been very important in pinning down elementary symmetries and elementary interactions effectively.

The facilities we have at our disposal are particle accelerators of somewhat more modest proportions than our high energy colleagues. At present we have nine national user facilities operated by the Department of Energy and the National Science Foundation. Eighty percent of our budgets go into support of those facilities. Two-thirds of that 80 percent goes into two major facilities, the Los Alamos Meson Physics Facility and the Bevelac at Berkeley.

There are, in addition, 12 small dedicated university facilities which are doing first-rate physics, but also play a key role in graduate student training.

Applications of nuclear physics to society have been manyfold. There are well-known applications to nuclear energy and defense; we don't want to talk about those here. Nuclear medicine was referred to earlier in these hearings, and that has been a major subfield of medicine, the fastest growing subfield of medicine in the last decade. It makes use of nuclei: properties of nuclei, radioactive isotopes, techniques of nuclear physics that were developed 20–25 years ago. This work was done originally for basic research purposes, without this end in mind; but as the properties became known, as the techniques became clear, it was often nuclear physicists familiar with these techniques and these properties who worked out and perfected the applications to society. One isotope is technetium-99; there have been 5 million applications a year for that isotope in medicine. So, I believe that the development of nuclear medicine, all by itself, is something that would justify the prior basic research that was done. There are many other applications, in ion implantation, many aspects of society and industry that I will not have time to go into.

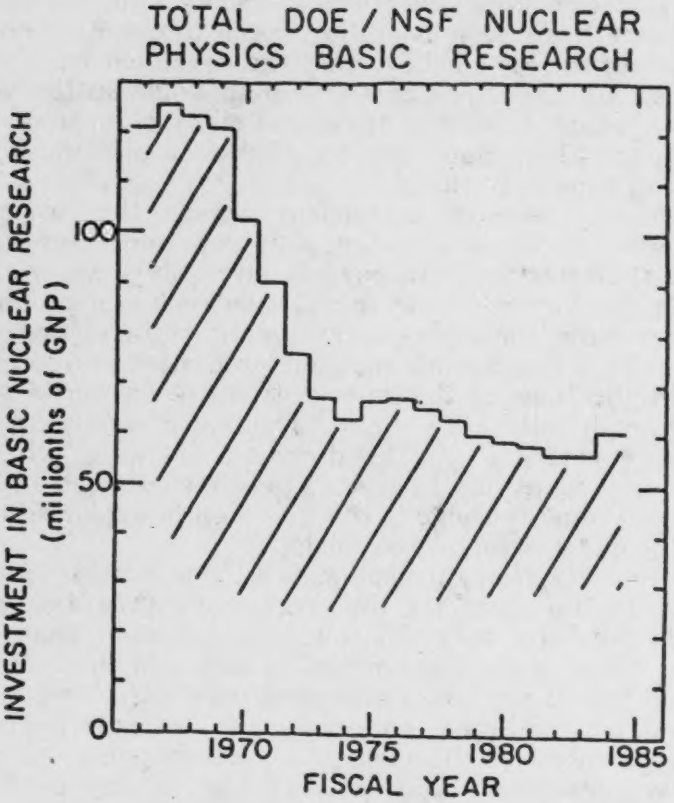
Beyond the ongoing research in nuclear physics that we are doing now, we saw in our long range plan two important new areas. One is on the interface with particle physics; we know and have known that the ingredients of nuclei, neutrons and protons, have internal structure, that the quark content of these protons and neutrons is critical in determining their properties as free particles. But the implications of this quark structure on nuclei has been shining through only very dimly. There are some experiments, pioneering experiments, in this direction, but we've felt for some time now—first identified 10 years ago—that an electron accelerator in the GeV energy range is the first step in exploring the implications of the quark structure in nuclei.

You will hear shortly from my colleagues, Drs. Austin, Holmgren, and McCarthy, on plans for that accelerator. We are very pleased to see, in the fiscal year 1985 budget submission, that the first step is being taken in the construction of such a facility.

We look beyond this in our long range plan. As nuclear matter is brought under higher and higher energy density, we expect—from theoretical considerations of the elementary constituents—to see qualitatively new phenomena occur at very high energy density. Such a state of matter, such energy densities, did not exist over any appreciable extended volume except in the very early instants of the universe, immediately after the big bang. We see a way for reproducing these conditions in the laboratory if we can produce relativistic heavy ion beams colliding with each other and producing a region of extended space in which we have energy densities, roughly a factor of 10 higher than those in normal nuclei. Under these conditions we expect qualitative changes to occur in the nature of nuclear matter. Exactly what these changes are we cannot predict, but theoretical expectations suggest that the dividing line between protons and neutrons would disappear, that there would be a transition to a new form of matter, which is referred to as a quark-gluon plasma. Whatever happens, we are getting into a new regime of nuclear matter that we feel should be explored, and we identified this as a major—the next major opportunity within the purview of our field.

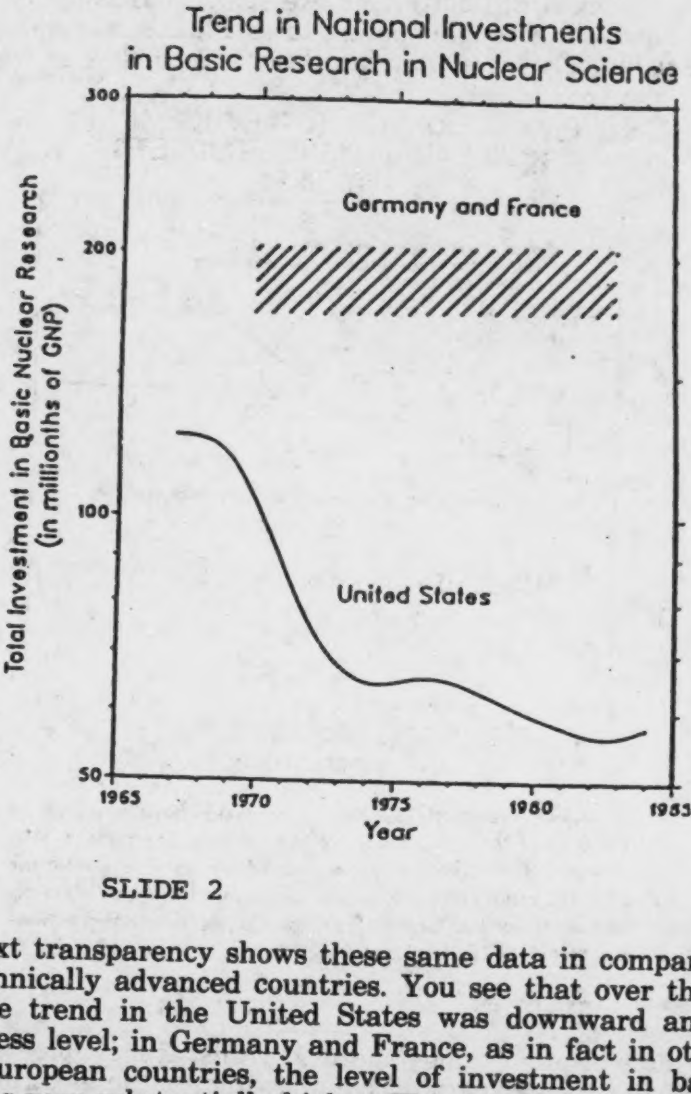
Now, I would like to talk briefly about the funding of our field. The United States has been the world leader in physical research and in nuclear physics for the last 25 or 30 years. How should one go about setting an absolute level of funding for basic research in an area of science?

May I have the first transparency, please?



SLIDE 1

Here we attempted to relate this level of funding in nuclear science to our total wealth, the gross national product. And what we have plotted here is the nuclear physics budget as a fraction of that gross national product. You see that from the levels that we had in the 1970's there has been a substantial decline which then has more or less leveled off over the last decade. There is a small sign of improvement in the last few years.



Trend in National Investments in Basic Research in Nuclear Science

SLIDE 2

The next transparency shows these same data in comparison to other technically advanced countries. You see that over the same period the trend in the United States was downward and then more or less level; in Germany and France, as in fact in other advanced European countries, the level of investment in basic research was very substantially higher. This is not something that is unique to our science; I believe that it is generally true for physical research all over, and it is beginning to have its effects.

In our long range plan we certainly couldn't aspire to funding levels of that order. What we tried to do, (recognizing that there was this discrepancy, and one might want to talk about initiatives to that level of investment in basic research)—we had to concern ourselves with what seemed reasonable, to try and come up with a minimal budget to maintain the vitality of nuclear science in the United States and to address some of the most urgent and important current issues.

An important point that I would like to make concerns the impact of these budgets on manpower, skilled manpower, that has been a contribution from nuclear physics to society, quite apart from the basic research. Many aspects of industry and government have absorbed talent, trained talent, from nuclear physics. Since 1970 the manpower rate, the number of Ph.D.'s trained, has declined by 50 percent in nuclear physics, as it has in physics all over. There is a real difficulty that we see in our country in the number of new young people coming in as Ph.D.'s; not only in nuclear physics, but physics in general. In fact, chemistry as well.

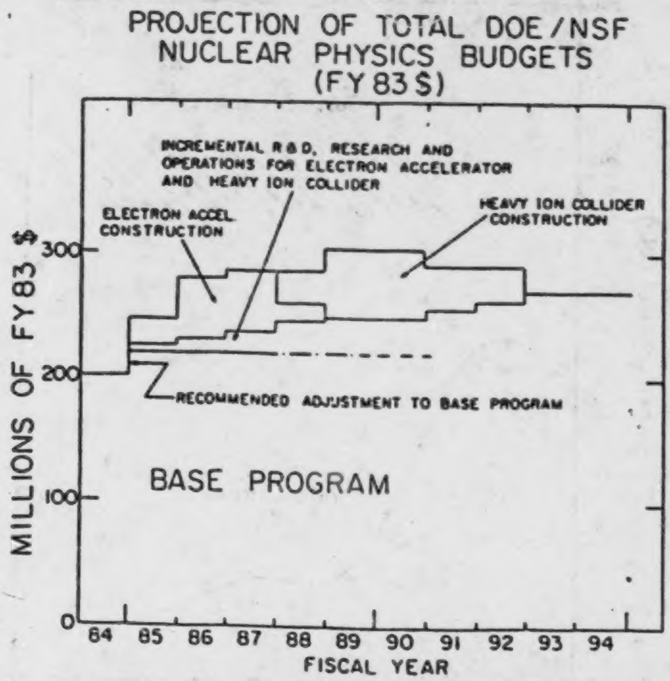


Fig. IV.5-D. Projected DOE/NSF budgets for basic research in Nuclear Science through 1994 in FY 1983 dollars. The present base program and the increment recommended by NSAC is shown for FY 1985. The estimated construction budgets for the 4-GeV electron accelerator facility and for the Heavy Ion Collider are shown as well as the incremental levels of operating funds.

SLIDE 3

In our budget projections—the next transparency, please—we try to look at the 10-year perspective allowing for the electron accelerator facility, allowing for the relativistic heavy ion collider, and recommending a one-time adjustment to the base program. Our current facilities in many cases are operating at 50 percent of what one may define as full utilization—not only in terms of the number of hours run but also in terms of the instrumentation, the control circuits, the manpower available for utilization. We thought that it was very important that at the same time that we talked about new facilities, we bring the level of operating funds and capital equipment funds to a level commensurate with what we have in hand now. Therefore there was a $20 million initiative a recommended adjustment to the base program, that is included in our long range plan for 1985.

DEPARTMENT OF ENERGY
NUCLEAR PHYSICS
(B/A IN MILLIONS OF DOLLARS)

OPERATING EXPENSES	APPROPRIATION FY 1983	APPROPRIATION FY 1984	PRES. BUDGET FY 1985
CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY	$ 0	$ 2.0	$ 5.0
SLAC INJECTOR OPERATIONS	0	0.1	1.1
SMALL BUSINESS INNOVATION RESEARCH	0 a/	0.8	1.4
ALL OTHER RESEARCH AND FACILITY OPERATIONS	118.9 b/	131.1 b/	137.1
TOTAL NUCLEAR PHYSICS OPERATING EXPENSES	$118.9	$134.0	$144.6

a/ DOES NOT INCLUDE $0.2 MILLION FOR SMALL BUSINESS INNOVATION RESEARCH

b/ INCLUDES $3.0 MILLION IN FY 1983 AND $3.0 MILLION IN FY 1984 WHICH WERE PROVIDED UNDER DEFENSE PROGRAMS FOR LAMPF FACILITY OPERATIONS

SLIDE 4

The next transparency shows levels of the fiscal year 1985 budget in DOE; we are very pleased and very grateful to see the new initiatives for construction. But in operating funds, the situation is very tight. As you may see, the operating funds, other than the initiatives on the top three lines, for all other research and facility operations in 1985—the budgets go to $137.1 million from $131.1 million—the amount is not even enough to take into account escalation.

We see the need for increased operating funds not only for the ongoing research program, but also as an investment in the future to stimulate young people to come into the field, to help with educational opportunities, and to make research careers more attractive.

Thank you very much.

[The prepared statement of Dr. Schiffer follows:]

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS

Statement of John P. Schiffer

Argonne National Laboratory and University of Chicago

Chairman, DOE/NSF Nuclear Science Advisory Committee

February 22, 1984

THE LONG RANGE PLAN FOR NUCLEAR SCIENCE AND THE DEPARTMENT OF ENERGY'S PROGRAMS IN NUCLEAR PHYSICS

Mr. Chairman and Members of the Subcommittee

My name is John Schiffer, I am a Senior Scientist at the Argonne National Laboratory, Professor of Physics at the University of Chicago, and am currently chairman of the DOE/NSF Nuclear Science Advisory Committee. I appreciate this opportunity to speak to you about basic research in nuclear science in the United States.

During 1983 our Committee prepared a *Long Range Plan* for Nuclear Science, in which we made specific recommendations on the future course and approximate funding levels for our field. We identify important opportunities and challenges that confront our science and I would like in this testimony to report to you on the outlines of this Plan and some of its implications for the nation's future in this science and for the DOE budget.

Nuclear science concerns itself with understanding the properties of atomic nuclei. Nuclei are the major component of the world in which we live. Our sun is a giant nuclear fusion reactor that provides the energy for all life in the biosphere, and this solar energy, as stored in wood, coal and oil has been the basis for the development of civilization. It is nuclear fission and fusion energy that our society has been attempting to tame during the last four decades as energy sources for future generations.

The drive to study, understand and control our environment has been the unique distinguishing characteristic of the human race -- it has become recognized formally by our society in its support for science. The enormous advances mankind has achieved in controlling the environment and improving the quality of human life are directly related to prior investments made in what at the time seemed in many cases to be pure and apparently useless basic science.

Nuclear science is a field of basic research that is still relatively young. The very existence of nuclei was discovered less than 75 years ago. We have made enormous advances in this field in the latter part of the twentieth century with much of the work coming from the United States. We now understand some of the basic elements of nuclear structure, of the simple modes of motion within nuclei, and the forces that hold nuclei together.

Nuclear physics and the techniques of nuclear physics can and do provide some very stringent tests of our theories of elementary interactions and of the fundamental particles and symmetries in nature. The important contribution of a U.S. nuclear physicist Professor William Fowler from the California Institute of Technology was recognized in the form of the 1983 Nobel prize in physics; Professor Fowler did pioneering work on the crucial role that nuclear reactions play inside stars and in determining the abundances of chemical elements in the universe, and trained an entire generation of nuclear astrophysicists.

There are a number of critical problems in nuclear physics that need to be studied and understood, fundamental questions on nuclear properties, forces, on nuclear symmetries, and nuclear interactions. We have facilities now which permit U.S. nuclear science to carry out many of these important investigations.

There are opportunities for major progress on the frontiers we share with our sister field of particle, or high energy physics. The quark-gluon picture of the strongly interacting elementary particles has been enormously successful in describing many properties of these particles. Since, in this theory, the protons and neutrons which are the constituents of nuclei consist of quarks and gluons, the implications of this substructure have profound consequences on our understanding of nuclei and must be explored. Such explorations generally require higher energy particle beams. Preliminary work in this direction is proceeding with our medium-energy facilities, and with the Los Alamos Meson Physics Facility (LAMPF) and Bates electron accelerator at MIT in particular. New information on particle (or quark) excitations in nuclei is beginning to be developed and the role of meson (quark-antiquark) exchange currents in the nucleus has been clearly demonstrated recently. But the use of the clean probe provided by energetic electrons in this quest has been the goal of the nuclear physics community for a decade. An electron accelerator with a continuous beam in the GeV energy range had been identified as the highest priority new facility for nuclear physics in the 1979 Long Range Plan of the Nuclear Science Advisory Committee, and was discussed in front of this Committee in 1980, 81 and 82 by Professor Herman Feshbach, my predecessor as Chairman of NSAC.

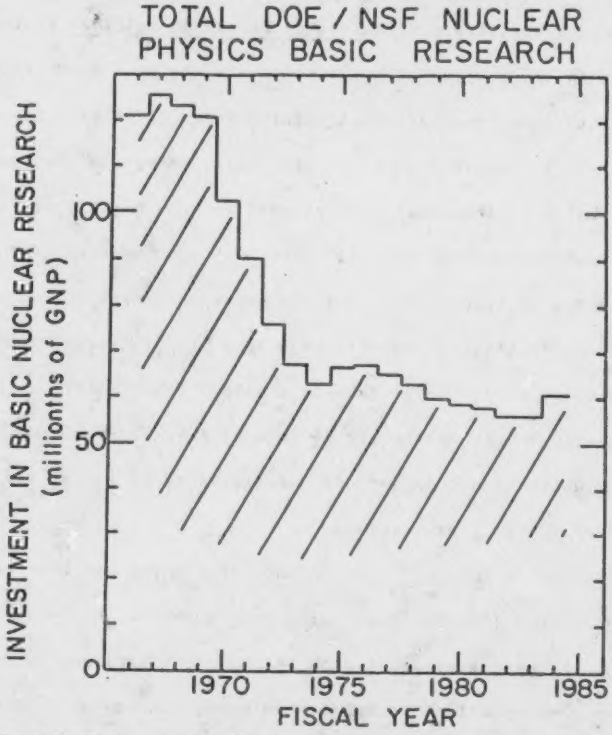
It is very gratifying to our science that in response to our Committee's recommendation last year, funds for such a new accelerator -- CEBAF -- now appear explicitly in the 1985 Budget Submission and we look forward anxiously to its timely realization.

Looking beyond the electron facility in our Long Range Plan, we see a major new opportunity for U.S. science in the investigation of the properties of nuclear matter at extremely high energy density, five to ten times that in normal nuclei. We have no present information of the properties of extended regions of matter with such energy content at densities which had been achieved in our universe only in the very early instants of the big bang. But these energy densities can be reached in the laboratory in the collision of two relativistic nuclei with energies on the order of 30 GeV per nucleon. Our present theoretical understanding implies that here qualitatively new phenomena should occur, for instance the clustering of the quarks and gluons into individual nucleons may disappear and entirely new forms of matter -- a quark-gluon plasma may be formed.

In our Plan we identify a relativistic heavy-ion collider as the highest priority within the purview of our science for the next major facility to be constructed, with the potential of addressing a new scientific frontier of fundamental importance. Current work on high-energy heavy-ion physics is being pursued at Berkeley at the Bevalac is planned for the near future in the USSR at the Dubna synchrophasotron, and will hopefully soon be carried out at somewhat higher energies at Brookhaven. But the new opportunity we see cannot be addressed at present facilities, it will require a very different more energetic tool, a heavy-ion collider. This is a unique opportunity, where we can test the fundamental theory of the strong interaction, study matter as it existed in the early universe and expand our understanding of nuclei and nuclear matter into an entirely new regime.

In the past decade funding of basic nuclear physics has been very severly constrained. Since 1970 the real purchasing power of the federal (DOE/NSF) investment in basic Nuclear Physics research has declined by between 25 and 40%. We have some excellent facilities in hand, but are so severely constrained in financial resources that they can be utilized to only a fraction of their capacity. The effects on human resources have been serious. The impact of funding constraints has taken its toll in the number of young people entering nuclear physics, as it has in other sciences. This is potentially a very serious matter and within our Plan we made a number of recommendations attempting to correct it.

A question that is difficult to answer is how a society should determine the appropriate rate for investment in basic research. This is an important matter of national policy and difficult to answer absolutely. We can, however, make a comparison with other economically advanced countries. To do this we calculated the DOE/NSF investment in basic nuclear research as a fraction of our Gross National Product. Historically this fraction has declined by almost a factor of two as may be seen in the figure below.



The total DOE/NSF budget for basic research in Nuclear Science since 1967 as a fraction of the Gross National Product.

Comparing our 1982 rate of investment to the similar rate in a group of European countries (that between them have over 80% of the population and GNP of the European Economic Community) and of Canada, we find that while the United States GNP was 3059 billion dollars, almost 30% more than the 2380 billion GNP for this comparable set of countries, our expenditures on basic nuclear research were $170 million in that year to compare with over 300 million dollars in these other countries; we spent 45% less. This difference is not unique in nuclear physics (though perhaps it is somewhat more severe), it is similar in other areas of basic physical research.

The high rate of European investment in research is beginning to pay off. European laboratories are generally far better equipped and staffed and they are competing more and more effectively with U.S. laboratories in productivity and quality of work. While current recognition, such as the 1983 Nobel Prize, reflects the momentum of our field gained in the late 1960's when U.S. funding for basic research was considerably higher, it is no accident that major new discoveries are now regularly coming from Europe and that a new generation of young, energetic and highly qualified European scientists is moving increasingly into the roles of international leadership.

It is important to point out that the rate of investment in basic research has a strong effect on our country's future in high technology, both in terms of the direct products of research and in terms of training young people in the advanced technologies of basic research who can then contribute their careers to applied research in industry and government.

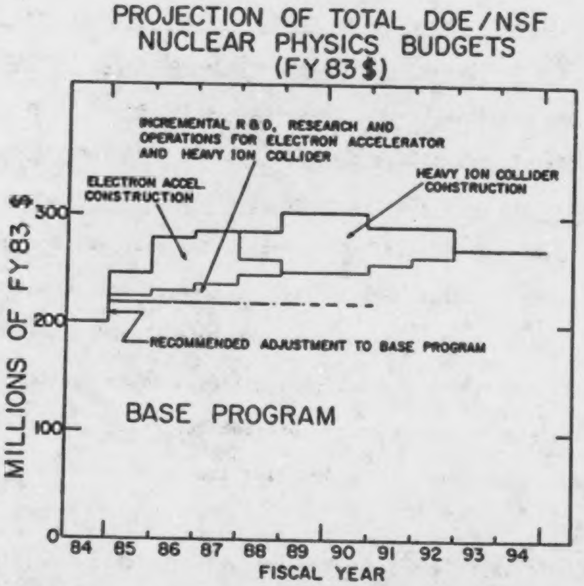
The contributions of nuclear physics to society have indeed been substantial beyond the well known application of fission to energy production and national defense. The use of nuclear techniques and nuclear materials is an increasingly important and pervasive part of diagnostic and therapeutic medicine, and indeed, nuclear medicine has been the fastest growing subfield of medicine. The savings in human lives and the improvements in the prevention and treatment of disease would alone justify the expenditures on the prior basic research. Isotopes were produced, characterized and classified and detection techniques were developed for basic knowledge in nuclear physics in the 1950's and 60's while the applications to medicine were conceived and developed much later. Nuclear physics and nuclear physicists contribute to society in many other areas. In energy production nuclear techniques play an important role not only through conventional nuclear energy but in a variety of other areas such as prospecting for oil and in energy conservation. The accelerators and experimental techniques developed in low-energy nuclear physics research are widely used by other sciences and by industry, for instance for ion implantation in the doping of semiconductor devices and in the fabrication of artificial articulating joints.

I want to stress that it is not only the impact of knowledge and techniques of basic nuclear science that has been important but the impact of the people whose skills and know-how was acquired by training in basic nuclear physics has often been a crucial element in the development of specific applications.

In our Long Range Plan, as in our specific earlier recommendation for the electron accelerator facility, we urged the Department of Energy and the National Science Foundation to recognize the inhibiting effects of fiscal constraints on the ongoing research in our field and pointed out that a one-time real increment of $20 million in operating and equipment funds is essential to ensure the continued vitality of our science. Present facilities in the United States are seriously understaffed and underutilized, operating because of budgeting constraints at a fraction of full capacity.

Instrumentation is in serious need of modernization. And university training of a new generation of scientists has to be strengthened. There is an immediate need for a significant injection of support to maintain the strength and balance of the nuclear research program.

Within the 1983 Long Range Plan for Nuclear Science we attempted to develop a coherent budget projection for the future. In this we allow for the present program (incremented as discussed above), the advent of the already approved electron facility, the recommended heavy-ion collider, and for associated costs.



Projected DOE/NSF budgets for basic research in Nuclear Science through 1994 in FY 1983 dollars. The present base program and the increment recommended by NSAC is shown for FY 1985. The estimated construction budgets for the 4-GeV Electron Accelerator Facility and for the Heavy Ion Collider are shown as well as the incremental levels of operating funds.

Finally, I would like to comment on the focus of these hearings, the FY 1985 Budget Submission for Nuclear Physics by the Department of Energy. The funding of our field comes almost 80% through DOE appropriations, so this budget is most important for our field. We are very pleased and enthusiastic to see in the FY 1985 budget a start on a national electron accelerator facility. We also see a reasonable and appropriate increase in capital equipment funds of $2.4M or 21%. But the remaining operating funds in the DOE Nuclear Physics Budget Submission increase by only 4.2%, an amount that represents a real decrease in purchasing power. This effective decrease means that the severe financial constraints that we perceived last year for our ongoing program are likely to become even more suffocating in FY85. New facilities and new capabilities are becoming available and it is becoming increasingly difficult to utilize them adequately. And very importantly our ability to educate the next generation of physicists is inhibited by the confinement of operating budgets. Considering the role of investment in basic research that we see in other technically advanced countries and the need to maintain the United States' position in technological and scientific leadership, it is clearly in our nation's interest to do justice to the scientific challenges facing us and to provide the resources to train a new generation of scientists who will help solve the problems of our country's future.

I would like to express my appreciation to this Committee for their recognition of the importance of basic research in the past and hope that you can assist us in continuing with this task.

Thank you very much.

Mr. FUQUA. Thank you.
Dr. Austin?

STATEMENT OF DR. SAM M. AUSTIN, DIRECTOR, CYCLOTRON LABORATORY, MICHIGAN STATE UNIVERSITY

Dr. AUSTIN. Mr. Chairman, I appreciate the opportunity to appear before the subcommittee to discuss the findings and recommendations of the NSAC Panel on Electron Accelerator Facilities, of which I was a member. I ask that my formal testimony be inserted in the record.

The principal recommendation of this subcommittee was that a new laboratory based on a linear electron-accelerator stretcher ring system capable of delivering intense, continuous electron beam in the energy range from one-half to 4 GeV be funded for construction at Newport News. It is this facility, originally proposed by SURA, which has found its way into the 1985 DOE budget in the form of a request for initiation of construction of the CEBAF at Newport News, Va.

The motivation for this facility is the probability of great advances in our understanding of the ultimate structure of matter. Dr. Schiffer has referred to these in his testimony, and I'll just comment that while this accelerator will be used for a variety of studies in nuclear physics, it is the opportunity to examine the impact of the quark substructure of the nucleus on nuclear phenomena which has motivated the major part of the facility proposal and which, in some sense, determined the characteristics of the accelerator which was recommended by our panel.

There has been interest in an electron accelerator for some time primarily because such an accelerator provides an extremely clean way to examine phenomena at the frontiers of physics. The electron is useful because it interacts in a weak, relatively gentle fashion with other particles of nature and also because it, itself, has no known substructure. For this reason, reports dating back to at least 1977 have recommended the construction of a continuous beam electron accelerator facility. By 1981 it had become clear to many people that such a facility should have a very high priority for the next construction item in nuclear science, and a panel was formed to first of all investigate the range of science which could be investigated, and also the nature of the facility required to do these investigations. The result was a strong recommendation for the construction of an electron facility able to achieve an electron energy of about 4 GeV.

In response to this recommendation, five proposals were received by late 1982, and the panel—whose recommendations I will discuss—was formed to assess these and to present its recommendations to the Nuclear Science Advisory Committee. This committee consisted of experimental and theoretical physicists with a broad range of expertise; technical experts on all the facility types involved; and also a number of individuals familiar with management of large scientific facilities. It was charged to determine which of these facilities would best meet the needs of the nuclear science program of the United States.

The deliberations of this committee were quite intense and thorough, and they are outlined both in the report of the committee and in my written testimony. I will not discuss them here in the interests of time. The fact is that the panel came to the principal recommendation that I have described earlier, and transmitted its report to the Nuclear Science Advisory Committee which, in turn, gave its full endorsement and the recommendation that construction be implemented without delay.

If this, the facility which presently appears in the Department of Energy budget for this year as a request for initiation of construction, is funded we will indeed have a unique, powerful tool for many studies in nuclear physics.

If I could have the last of the transparencies that I gave you?

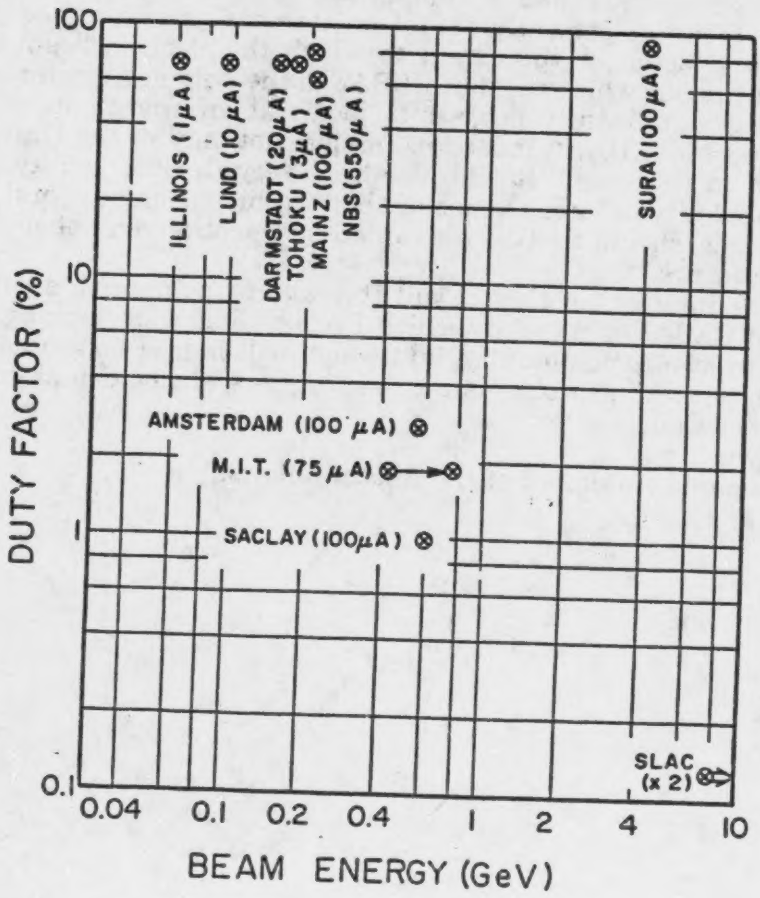


Figure 2. Characteristics of electron accelerators operating or under construction in 1983.

This transparency shows a comparison of the CEBAF facility with other facilities presently extant, in terms of the beam energy and the duty factor, or the extent to which the electron beam is, indeed, continuous. One sees that CEBAF is the only accelerator facility with a significantly large duty factor at an energy above a few hundred MeV. It will indeed be unique, not only in the United States, but in the world. It will also be a very flexible facility. It has the capability of later expansion, both to higher energy, and to further beams, should that be warranted by the observed phenomenon in the future.

So, in the interests of time, I will stop at this point with a summary: that CEBAF is a facility which I believe has wide backing in the nuclear science community, and which will indeed be a unique facility for attacking problems on the frontiers of nuclear physics in the next decade.

Thank you.

[The prepared statement of Dr. Austin follows:]

STATEMENT BEFORE THE SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS
of the
House Committee on Science and Technology

February 22,1984

Sam M. Austin

I appreciate this opportunity to appear before the Subcommittee to discuss the findings and recommendations of the Nuclear Science Advisory Committee (NSAC) Panel on Electron Accelerator Facilities. I am Professor of Physics and Research Director of the National Superconducting Cyclotron Laboratory at Michigan State University and have been Chairman of the Division of Nuclear Physics of the American Physical Society and a member of NSAC. I served on the NSAC Panel whose findings I will discuss today.

I will first describe the principal recommendation of the Panel and the scientific opportunities that motivated this decision; then describe briefly the background that led to the formation of the Panel and the operations of the Panel and finally turn to the implications of the Panel's recommendations for nuclear science.

PRINCIPAL RECOMMENDATION

The Panel on Electron Accelerator Facilities, following detailed consideration and study of proposals submitted to it, recommended that the proposal submitted by the Southeastern Universities Research Association (SURA) be accepted and funded for the construction of a new facility centering on a 4 GeV accelerator-stretcher ring system capable of delivering intense, continuous electron beams in the energy range from 500 to 4000 MeV. It is this recommendation that is incorporated in the DoE Budget Request for 1985 in the request for initiation of construction of a Continuous Electron Beam Accelerator Facility(CEBAF) at Newport News, Virginia.

SCIENTIFIC OPPORTUNITIES

The Panel's decision was motivated by the possibility of great advances in our understanding of the ultimate structure of matter. It has been known since the 1930's that the nuclei found at the center of atoms are built up mainly from neutrons and protons; more recently it has been found that other particles, such as pi mesons, transiently present in the nucleus also play an important role. However, it is the realization that all these particles have a substructure, and are built from combinations of the elementary quarks,that has caused a revolution in our understanding of nuclear structure. It now seems possible that a fundamental theory of the nucleus, in terms of the ultimate quark degrees of freedom may be achievable. Moreover, nuclear studies will shed light on crucial questions: how quarks are confined inside protons and neutrons and whether nuclei contain quark configurations more complex and exotic than those one might encounter in the high energy collisions of elementary particle physics. It then appears that studies in nuclear and elementary particle physics are complementary approaches to reaching an understanding of the fundamental nature of matter.

When attacking frontier problems of this sort it is helpful if the probing projectile is itself well understood, so information about the target nucleus can be extracted from the data with minimum ambiguity. In this regard the electron projectile is especially favorable: it has relatively weak and well known interactions with other particles and appears to have no substructure of its own.

For these reasons CEBAF will be capable of a very wide range of studies in nuclear science. However, it is the interest in studies on the boundary between nuclear and elementary particle physics that determines its most important characteristics. A broad range of energy up to about 4 GeV is necessary to permit study of the transitions from the low energy region where the phenomena are describable in terms of neutron and proton nuclear constitutents, to the intermediate energy region where the quark substructure of the nucleus is expected to be important and finally to the high energy region where the phenomena are almost independent of whether the protons and neutrons are free or are bound up in nuclei. Anchors in the well understood regions at low and high energies will permit a confident interpretation of the results of measurements in the quark-nuclear- physics domain of greatest interest. A continuous electron beam is required to permit the simultaneous detection of several particles from a single nuclear collision; such coincidence measurements are necessary to extract the effects due to the quark substructure from a plethora of background events. Indeed, coincidence measurements are necessary for by far the largest part of the anticipated program of the accelerator.

HISTORICAL BACKGROUND

Interest in a high energy continuous electron beam accelerator has found official expression in a joint DoE/NSF study on the Role of Electron Accelerators in U.S. Medium Energy Nuclear Science(Livingston Report-1977) and in a National Research Council Report on the Future of Nuclear Science(1977). The 1979 Long Range Plan for Nuclear Science prepared by NSAC contained a specific recommendation for a continuous beam electron accelerator with energy in the 1-2 GeV range, with construction beginning in 1985. By 1981, the new views of the nature of the nucleus, combined with a long term appreciation of the power of the electron as a probe of nuclear structure led many to feel that an electron facility had a high priority for the next large construction project in nuclear science. Recognizing this, an NSAC Subcommittee on The Role of Electromagnetic Interactions in Nuclear Science was formed and made a new assessment of the scientific objectives of the national program for research with electromagnetic probes and the technical capability required to meet these objectives. This Subcommittee found that: "qualitatively new opportunities, leading to a more fundamental understanding of nuclear physics" would become available with the development of a high energy , high intensity, continuous electron beam accelerator facility and strongly recommended construction of a facility able to achieve an electron energy of about 4 GeV.

In response to this recommendation, five proposals were submitted to the DoE and NSF; a Panel on Electron Accelerator Facilities was formed at an NSAC meeting on January 12, 1983, and charged to "Examine each of the proposed facilities as a possible component of the overall program of basic nuclear research and recommend the facility or combination of facilities which will best meet the United State's needs for basic nuclear research with electromagnetic probes." After a detailed study and consideration of these proposals, the Panel arrived at several recommendations including the principal recommendation stated above. The report of the Panel was submitted to NSAC and was transmitted to the DoE and NSF on April 29,1983, with the"full endorsement" of NSAC and the recommendation that "it be implemented without delay."(See Appendix I).

Most recently, NSAC, in its 1983 Long Range Plan For Nuclear Science, reaffirmed its earlier recommendation for the earliest possible start on the construction of a national electron accelerator laboratory and noted that the "new 4 GeV electron accelerator ...is clearly the major near-term new initiative in nuclear physics."

THE PANEL ON ELECTRON ACCELERATOR FACILITIES

The Panel on Electron Accelerator Facilities consisted of thirteen individuals, including the Chairman, D. Allan Bromley. In addition to experimental and theoretical physicists with a broad range of experience in nuclear science, it included individuals with first hand technical knowledge of all the types of facilities under consideration, and others familiar with the technical management of large facilities. The Membership of the Panel is given in Appendix II. I believe that the overall technical knowledge and competence of the Panel was well suited to carrying out its charge, which was

> " Within the context of (1) the December, 1979 "Long Range Plan for Nuclear Science" ; (2) the scientific discussion of the NSAC Subcommittee on Electromagnetic Interactions report "The Role of Electromagnetic Interactions in Nuclear Science" and (3) your own best scientific judgment, review and evaluate the electron accelerator facility proposals submitted by Argonne National Laboratory, University of Illinois,Massachusetts Institute of Technology, National Bureau of Standards, and Southeastern Universities Research Association. Examine each of the proposed facilities as a possible component of the overall national program of basic nuclear research, and recommend the facility or combination of facilities which will best meet the United States needs for basic nuclear research with electromagnetic probes. "

A technical subpanel was formed and made site visits to the proposing institutions; this subpanel was charged "with a detailed examination of the technical and accelerator physics aspects of each proposal and an expert evaluation of its feasibility, the adequacy of the RandD already accomplished, the nature of that remaining to be accomplished .." Each of the proposing institutions was given the opportunity to address weaknesses perceived in the other proposals. This was done in writing and at a public meeting of the Panel held in Washington February 17 -19. Further meetings of the Panel were held on February 19, March 7 and March 30, resulting in the principal recommendation referred to above and other recommendations listed in Appendix III.

THE CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY

There are presently a large number of continuous beam(or high duty cycle) electron accelerators in use or under construction throughout the world. (See Figure 1). However, in its combination of energy and duty cycle the CEBAF has unique characteristics as shown in Figure 2. It will have capability for the study of nuclei with electron probes that is unmatched in the world, and will address the questions of the nature and importance of the quark substructure of nuclei that are destined to be a new frontier of nuclear physics in the coming decade.

By the nature of its design the CEBAF has great flexibility for the future; it not only meets an important present need, but can serve as a base for additional future capability. Should the phenomena encountered warrant it, the facility can be expanded toward higher energies or additional continuous beams can be provided.

The SURA Universities are committed to provide a total of at least 35 additional tenure stream positions in nuclear physics, upon approval of the CEBAF. These positions represent a significant increase in total university involvement in nuclear physics and should yield an increased flow of young highly trained nuclear scientists to provided the manpower needed to address the frontier problems discussed here and to contribute to the needs of the nation for highly qualified technical manpower.

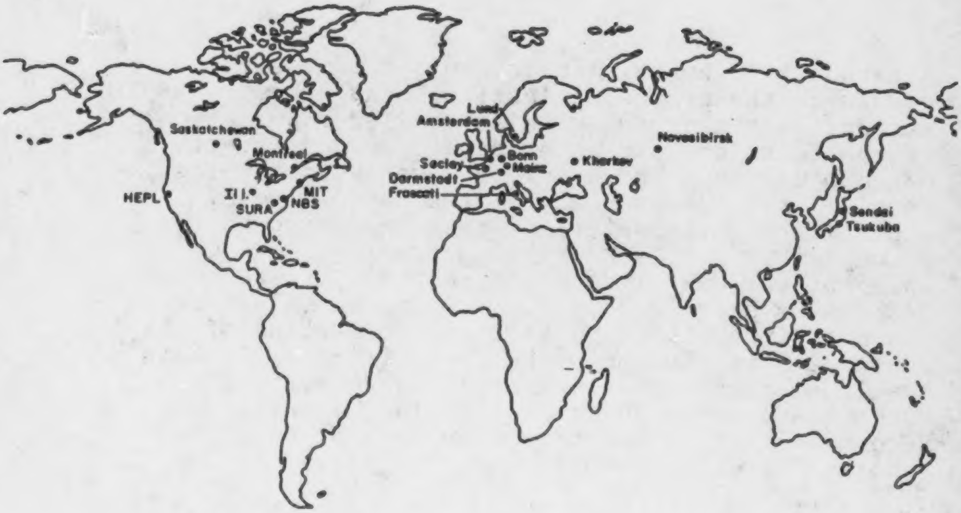

Saskatchewan
Montreal
HEPL
Ill.
SURA
MIT
NBS
Lund
Amsterdam
Saclay
Darmstadt
Frascati
Bonn
Mainz
Kharkov
Novosibirsk
Sendai
Tsukuba

Figure 1. World distribution (1983) of continuous beam electron accelerator projects.

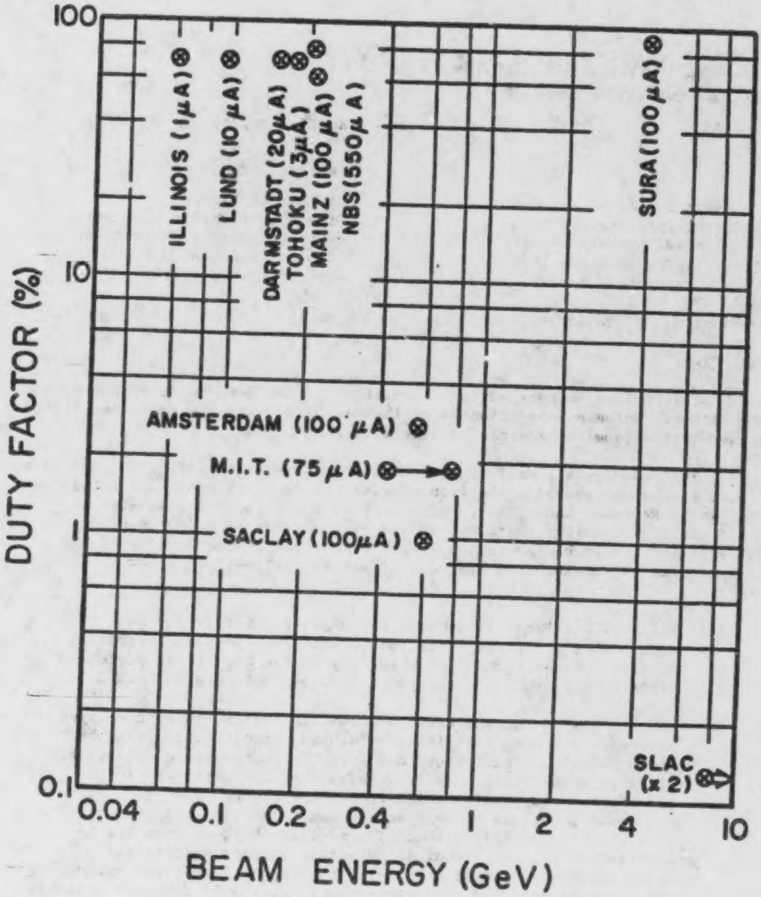


Figure 2. Characteristics of electron accelerators operating or under construction in 1983.

APPENDIX - I

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

Telephone 312/972-4066

April 29, 1983

Dr. James E. Leiss
Associate Director for High
Energy and Nuclear Physics
Office of Energy Research
U.S. Department of Energy
ER-23 GTN
Washington, DC 20545

Dr. Marcel Bardon
Director, Division of Physics
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Dear Sirs:

The Nuclear Science Advisory Committee of the Department of Energy and the National Science Foundation herewith transmits, with its endorsement, the report of the Panel on Electron Accelerator Facilities.

This panel was formed at an NSAC meeting on January 12, 1983, and asked "...to review and evaluate electron accelerator facility proposals submitted by Argonne National Laboratory, University of Illinois, Massachusetts Institute of Technology, National Bureau of Standards, and Southeastern Universities Research Association." The essentials of the Panel's recommendations, quoted from the report, are as follows:

> "This Panel finds that the highest priority for new accelerator construction in the U.S. nuclear physics program is for an electron accelerator of high duty factor capable of producing beams at any energy in the range from 500 MeV to 4000 MeV.
>
> "That being the case, we consider the two fully developed proposals for such facilities before us, namely those from the Argonne National Laboratory and from the Southeastern Universities Research Association. It is a measure of the strength of the electromagnetic physics community in the country that two quite different proposals of this scope, magnitude, and quality are available for consideration. The decision between them has been a difficult one. The Technical Subpanel, after a very careful, independent analysis of both designs, has concluded that both designs are feasible ones and that either could very well form the basis for an extremely powerful national facility.
>
> "Our decision between the two proposals then depends upon the relative weightings that we ascribe to the different problems facing the two groups of accelerator designers and to other considerations quite apart from technical ones. With such considerations in mind the Panel recommends:

U.S. Department of Energy The University of Chicago Argonne Universities Association

> That the proposal of the Southeastern Universities Research Association (SURA) for the construction of a linac-stretcher ring accelerator system capable of providing high duty-factor beams throughout the energy range from 0.5 to 4.0 GeV be accepted and that this facility be constructed and designated the National Electron Accelerator Laboratory (NEAL)."

The priority NSAC attaches to the construction of an electron accelerator of high duty factor in the few GeV range is the culmination of plans made over the past decade. The role of such an electron accelerator in nuclear research was emphasized in the Long Range Plan for Nuclear Science, presented to and accepted by DOE/NSF in 1979, and in numerous committee reports, starting with the 1977 report of the DOE/NSF Joint Study of Role of Electron Accelerators in U.S. Medium Energy Nuclear Science (the Livingston report).

Nuclear physics is entering a period of expanding horizons; this presents an opportunity to shed new light on problems of long standing and to ask questions that could hardly have been imagined 15 years ago. The support for a 4 GeV CW electron accelerator should not obscure the fact that nuclear physics faces other scientific challenges and opportunities. This Committee shall place these in perspective as part of the new Long Range Plan for Nuclear Science to be completed in 1983.

In recommending a major new facility, it is essential also to recommend measures to ensure the continued growth and vitality of the research community that will use it. What is said here applies not only to the electromagnetic physics community but to the nuclear physics community as a whole. Major facilities in the United States are seriously underutilized, operating because of budgetary constraints at a fraction of full capacity. Much of their instrumentation is in serious need of modernization.

Accordingly, in addition to incremental funding for the construction and operation of the new electron accelerator, there is an immediate need for a significant injection of support to maintain the strength and balance of the nuclear research program. This will require some $20 million per annum in incremental operating and equipment funds.

In conclusion, the Committee sends you the Report of the Panel on Electron Accelerator Facilities with its full endorsement, and recommends that it be implemented without delay.

On behalf of the Nuclear Science
Advisory Committee,

John P. Schiffer
Chairman

JPS/bw

Enclosure

APPENDIX - II

Membership of the NSAC Panel on Electron Accelerator Facilities

Sam M. Austin (Michigan State University)*

D. Allan Bromley (Yale University), Chairman of Panel

Joseph Cerny (Lawrence Berkeley Laboratory)

Karl A. Erb (Oak Ridge National Laboratory)*

Hermann A. Grunder (Lawrence Berkeley Laboratory), Chairman of Technical Subpanel*

Ernest M. Henley (University of Washington)

Steven E. Koonin (California Institute of Technology)

Arthur B. McDonald (Princeton University)

Philip L. Morton (Stanford Linear Accelerator Center)*

Richard B. Neal (Stanford Linear Accelerator Center)*

Ednor M. Rowe (University of Wisconsin)*

Ingo Sick (University of Basel)

Arie van Steenbergen (Brookhaven National Laboratory)*

* Members of the Technical Subpanel.

APPENDIX III

MAJOR RECOMMENDATIONS OF THE PANEL ON ELECTRON ACCLERATOR FACILITIES

That the proposal of the Southeastern Universities Research Association (SURA) for the construction of a linac — stretcher ring accelerator system capable of providing high duty factor beams throughout the energy range from 0.5–4.0 GeV be accepted and that this facility be constructed and designated the National Electron Accelerator Laboratory (NEAL).

That SURA management, in consultation with DOE and NSF, appoint a National Advisory Board (NAB) as soon as possible and that the members of this Board be engaged in all major decisions affecting the structure and future of the National Electron Accelerator Laboratory.

That very soon after formal approval of NEAL, its management, with the advice of its National Advisory Board, announce a formal solicitation of experimental proposals and the creation of a Program Advisory Committee (PAC).

That potential users of NEAL be encouraged to develop proposals for utilization of SLAC for consideration by the appropriate Program Advisory Committee, and that DOE/NSF give high priority to provision of the necessary support for those experiments that are accepted, in order that a significantly larger fraction of the U.S. electromagnetic physics community gain access to, and experience from, experimental studies with higher energy electron beams that have hitherto been available to it.

That SURA and NEAL management consider the possible advantages of relocating NEAL to provide improved access to one or more major university campuses and to one or more major airports, providing that this can be accomplished without significant increase in the total project cost.

Mr. **Bateman**. Thank you very much.

The next panelist this morning is Prof. Harry D. Holmgren, who is president of the Southeastern University Research Association and member and head of the Department of Physics and Astronomy at the University of Maryland. Dr. Holmgren, it's a pleasure to see you again and to have you before the committee. I've just commented that it doesn't speak too well for our attendance when I get to preside, but it's a pleasure to greet you.

Dr. **Holmgren**. I'm very pleased to be promoted to the chairmanship of the Physics Department at Maryland. I'm simply—actually, just one of the professors there.

STATEMENT OF DR. HARRY D. HOLMGREN, PRESIDENT, SOUTHEASTERN UNIVERSITIES RESEARCH ASSOCIATION, DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF MARYLAND

Dr. **Holmgren**. I would like to just very briefly summarize some of the things that have been happening in the SURA organization and leave a little bit more time to Dr. McCarthy, who is the Acting Director of the CEBAF project and who can tell you more about the exciting physics and the accelerator plans that we have been developing.

SURA, as they call the Southeastern Universities Research Association, is a consortium of over 25 universities in the southeast area of the country. The structure of our organization is patterned very much after the Universities Research Association which manages Fermi Lab which, we believe, is one of the most successful laboratories in this country. So we think we couldn't pattern our organization after a better example.

I'd like to point out that although SURA is rather new, we were incorporated in late 1980, scientists at member institutions of SURA—Dr. McCarthy and others—have played a role as leaders in this area of science, of using high energy electron beams to explore the structure of atomic nuclei. Their work provided much of the impetus for the scientific community to provide the recommendation that we should build a 4-GeV facility. People such as Dr. McCarthy have been contemplating such a facility for over a decade; and as a result of his efforts, design work, his studies, he has brought into existence the SURA organization which has now pooled the resources of our 25 or more universities to support this project and to get it started.

Since the time that the Bromley Panel's recommendation was endorsed by the Nuclear Science Advisory Committee, the SURA organization and the design work at the University of Virginia have made considerable progress using the resources of our universities and the resources of our States which are represented by the universities, and certainly the Commonwealth of Virginia has been the primary contributor in terms of the states.

I think the rest of the progress of the SURA organization is summarized in my written report, and I would like to yield the floor to Dr. McCarthy.

[The prepared statement of Dr. Holmgren follows:]

Statement before the Subcommittee on
Energy Development and Applications
House Committee on Science and Technology
Harry D. Holmgren
February 22, 1984

My name is Harry Holmgren. I am the President of the Southeastern Universities Research Association (SURA). I am here today to discuss SURA's plans for the Continuous Electron Beam Accelerator Facility (CEBAF). I am also accompanied by Dr. James McCarthy of the University of Virginia, the originator of the SURA proposal and Acting Director of CEBAF, who will tell you about the exciting science and the facility plans. I would like to tell you briefly about the SURA organization and summarize some of the progress we have made since the Bromley Panel's recommendation in April 1983.

SURA is a consortium of more than 25 universities located in the Southeast, registered in Virginia as a non-profit corporation. The structure of the organization is patterned very much on the Universities Research Association which manages the Fermi National Accelerator Laboratory. The basic infrastructure of the organization is essentially in place and we are prepared to enter into an initial R&D contract with DOE in the immediate future.

Although the SURA organization has been in existence for less than four years, Dr. McCarthy and faculty members at other SURA institutions have played a major role for more than a decade in providing the scientific justification that led the U.S. nuclear science community to recommend a 4 GeV electron accelerator. The groups at the American

University and the University of Virginia carried out many of the early experiments at SLAC using high energy electron beams to study the properties of atomic nuclei. Faculty members at other SURA institutions carried out many of the early theoretical analyses of these experimental results, which demonstrated that the constituent neutrons and protons of nuclei had to be considered themselves as composite particles made of quarks. The groups at American University and the University of Virginia also spearheaded the effort to install the new injector at SLAC for nuclear physics studied.

Dr. McCarthy organized a conference of the leading international accelerator experts at the University of Virginia in 1979. The results of that conference indicated that a 4 GeV continuous beam electron accelerator could be built using existing technology and that it was not necessary to await the outcome of time-consuming studies of new types of acceleration systems. SURA submitted an initial proposal for a 2 GeV electron accelerator, with plans for upgrading to 4 GeV, to the DOE and NSF in 1980, two years before similar proposals were submitted by competing groups. In spite of the recent origins of the formal SURA organization, representatives of our member institutions have a long history of using high energy electrons to study nuclei and have played an important part in planning the new facilities needed to investigate this exciting new frontier of physics at the interface between nuclear and particle physics.

Since the Bromley Panel report was accepted by NSAC in April 1983, we have used university and Commonwealth of Virginia funds to continue to refine the design and the cost estimates for both the accelerator and conventional construction. We have made extensive use of outside consultants from SLAC and elsewhere. We contracted with an A&E firm to develop more detailed designs and cost estimates for the conventional construction. We have employed the services of William Brobeck and Associates to re-estimate and update the cost of the accelerator and related systems. A Conceptual Design Report for CEBAF is essentially complete. After a detailed technical review of this report by the DOE in late February, we expect to establish a Total Estimate Cost for CEBAF.

Following the recommendations of the Bromley Panel report, SURA reconsidered its original site at Newport News. A Site Committee, consisting of four SURA Board members and three scientists from outside SURA, including one former Bromley Panel member, reviewed sites at Charlottesville and Blacksburg in addition to the one at Newport News. The Committee reaffirmed SURA's earlier selection of Newport News: the two buildings at Virginia Associated Research Campus (VARC) and the former Space Radiation Effects Laboratory (SREL) represent a substantial savings to the projects. The site is serviced by three airports: the Patrick Henry Airport, within three miles of the site, provides convenient commuter service to many East Coast cities; a major airport at Norfolk, less than 30 minutes drive by interstate, provides direct flights to cities throughout the United States; and the Richmond airport, approximately one hour by interstates, provides alternate connections. The VARC building provides approximately 23,000 square feet of office and laboratory space, in addition to shop space and will allow an immediate buildup of the staff. The SERL building, when renovated, will provide an additional 13,000 square feet of office and laboratory space in addition to 40,000 square feet for shops and services facilities.

The buildup of the CEBAF staff has had to await the decision of the

President to include CEBAF in the FY 1985 budget and the availability of initial R&D funds from the DOE. The search for a director has been progressing. Several possible candidates have been identified and I am currently negotiating with a specific candidate. Our objective is to have a permanent director in place by July 1984. Approximately 100 applicants have been received for various positions at CEBAF. A number of possible candidates for senior positions have been identified. A major emphasis will be placed on the recruitment of these persons over the next few months as well as junior persons who will participate in a training program at SLAC.

Funds for five Governor's Distinguished CEBAF Professorships, four other senior positions, and eleven junior personnel are expected to be provided by the Commonwealth of Virginia starting July 1, 1984. Other support provided by the Commonwealth brings their total contribution to more than $1.5 million per year for the next two years. The support for the nine senior positions and 17 additional state positions is expected to continue for the life of the project with the five Distinguished Professorships carrying the equivalent of university tenure.

SURA member institutions have been actively recruiting new faculty members with expertise or interests in the use of high energy electromagnetic probes. Existing faculty have taken sabbaticals at SLAC to gain experience. New programs in the field are developing at various member institutions.

SURA, in consultation with the DOE and NSF, appointed a National Advisory Board (NAB). The membership includes ten distinguished nuclear and particle physicists, representing most U.S. laboratories as well as two European laboratories. The NAB advises the laboratory and SURA management on decisions affecting the structure and future of CEBAF. The NAB held its initial meeting in July 1983. A second meeting was held at Newport News on January 30, 1984. The organization of a formal Program Advisory Committee (PAC) is expected to occur near the end of 1984 in order to help plan the initial experiments.

SURA has held a series of workshops involving approximately 100 scientists to plan the initial experimental facilities. An intensive one-week workshop is planned in June 1984. The formal User's Organization is being set up and is expected to be incorporated this Summer.

UNIVERSITY OF MARYLAND
Department of Physics and Astronomy
College Park, Maryland

Curriculum Vitae

Harry D. Holmgren
Professor of Physics

I. Education:

B.S.	University of Minnesota, 1949
M.A.	University of Minnesota, 1950
Ph.D.	University of Minnesota, 1954

II. Experience in Higher Education:

1961-65	Associate Professor, University of Maryland
1965-78	Director, Cyclotron Laboratory, University of Maryland
1965-	Professor, University of Maryland
1980-	Appointed Trustee and elected President, Southeastern Universities Research Association

III. Experience Other than Higher Education:

1954-61	Physicist, Naval Research Laboratory

IV. Publications:

See Attached List

V. Professional Activities:

Fellow of American Physical Society
Philosophical Society of Washington
Sigma Xi
Washington Academy of Science
Phi Beta Kappa

VI. Honors and Awards:

AEC Pre-doctoral Fellowship, 1950-54
Phi Beta Kappa
E. O. Hulbert Award, Naval Research Laboratory, 1960
Arthur A. Fleming Award, Outstanding Young Scientists in Government, 1961
Maryland Academy of Science, Honorary Member, 1971
NATO Postdoctoral Fellowship, 1973
Chercheur Associe, University of Paris at Orsay, 1973
Distinguished Visiting Scientist, University of Paris at Orsay, July 1974

Mr. BATEMAN. And with that, then, it is again a distinct pleasure to have Dr. McCarthy with us this morning. Dr. McCarthy has done yeoman service to SURA and, I think, to the physics community in America in being the conceptual father of the 4-GeV continuous electron beam accelerator, and we are very pleased to hear from Dr. McCarthy.

STATEMENT OF DR. JAMES S. McCARTHY, ACTING DIRECTOR, CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY, DEPARTMENT OF PHYSICS, UNIVERSITY OF VIRGINIA

Dr. McCARTHY. Thank you. I fortunately can shorten some of my statements because my colleagues have covered many of these items, particularly the value to nuclear science of this facility and what it means to the future of nuclear physics in this country.

I come to you wearing the hat of acting director of the Continuous Electron Beam Accelerator Facility. As stated earlier, this accelerator has been wanted by the physics community for many years, almost two decades that we're approaching, of the desire and need for such a facility.

The nucleus and the fundamental processes that take place within this dense and small region of space are important aspects of our universe. This accelerator is a basic research tool; it is dedicated to basic research and studies of the constituents of the nucleus and the forces by which they interact. Even though the accelerator itself is a complex and large device, it is still a precision instrument. The electron in particular, when used as a certain probe of the nuclear interior, has very significant advantages. Of primary importance is that the electron interacts with the nuclear constituents only through the electromagnetic force, and permits a precise and quantitative understanding of the nuclear structure. By increasing the electron energy one is able to investigate increasingly smaller distances within the nucleus. That is one of the reasons why the maximum energy of this proposed facility plays such an important role in determining the planned experimental program.

As stated many times, nuclear physics is really on the threshhold of new developments which promise to change completely our picture of a nucleus and the theoretical tools with which we try to describe its behavior. This is certainly connected with recent results—the continuing, exciting results—that particle physicists are discovering, that we now must take into consideration that the protons and nucleons which have formed the basis of our past descriptions of nuclear physics, and the nucleus itself, are composed of constituents themselves.

But we also have to realize that the nuclear medium is a more complex medium, that the simplicity of the fundamental underlying theory can only be gotten at by a variety of experimental methods, and that many of these experimental methods require very sophisticated techniques in the experiments. And this accelerator has been designed to try to permit these techniques to be fully utilized, in particular, the use of coincidence-type measurements to look at not only the electron coming out of the nucleus, but the many particles that it has interacted with. And this is clearly the major motivation; it is the major change in this type of facility design.

The electron probe is an ideal probe in the sense that it is weakly interacting with the nucleus. We can hope to try to understand the interactions that took place. But because it is weakly interacting, that means that the cross sections or the rates of reactions are very low. This can be compensated for by increasing the beam current, which is another important criteria for the facility. The existing electron beams at high energy can produce high currents, but they do not—they have that fundamental limitation because of the existing technology of which they were built, that the beam comes in pulses.

This accelerator attempts to use state-of-the-art technology, both in the pulse accelerating techniques and in the storage ring designs, to produce a continuous beam in time. So, the major goal of this facility is to produce a high energy—4 GeV or greater—continuous beam in time, and as high in average current as possible with existing technology.

As stated earlier, during the past several years an active and intense research program has taken place at universities and national labs to develop an accelerator design that would meet these goals. I think that the effort expended by the nuclear physics community is indicative of the value placed on the physics program and the need for such a facility.

I would refer to a conceptual drawing of the facility which is in the written testimony which shows the present design status of the CEBAF facility. It basically consists of a pulsed linac very similar to the existing one at the Stanford Linear Accelerator Center with upgraded klystrons and cavity design. It also attempts to take a storage ring design, but with certain modifications, modifications in the sense that turn the standard storage ring which store beams for significant lengths of time, hours or greater, into a stretcher storage ring where the beam is in there on an average of less than a thousandth of a second. It takes the pulses that are coming from the Linac, which are approximately one-millionth of a second in length which are going nearly the speed of light, which corresponds to approximately 300 meters in space, and converts that 300 meters in space to a continuous beam by folding the head of the beam back around to the tail inside the stretcher storage ring. And so the concept is, essentially, very simple. We take a pulse beam and convert it into a stationary, time-consistent beam that can be extracted as it is waiting for the next linear pulse to come from the accelerator.

It has significant advantages for expansion capabilities; it can supply simultaneous beams to many experimental areas. The present facility has three experimental areas planned in the initial scope of the project. But it has the option for additional experimental areas, additional rings, particularly when we have that high-powered linac available for filling these rings.

Since the Bromley Panel's recommendation that our proposal be accepted, we have continued working very hard on the project, as Harry had stated. We have used Commonwealth funds and university funds to do a complete reevaluation of the cost, a continuing reevaluation of the technical feasibility and scope of the project, and we are right now in the midst of intense negotiation with the Department of Energy about costs and scope, and I think we have made significant progress during the last year, and we have learned a lot. I think that this project is important for the future of nuclear science in this country, and I'm enthusiastic and I am honored to have to have the enthusiasm of these major universities and States who have supported this. This project is rather unique. Since its conception until its final acceptance it was funded primarily by private resources of the States and universities, and I think that's a unique occurrence in a facility of this magnitude.

Let me conclude by thanking you and for the opportunity to discuss the project with you.

[The prepared statement of Dr. McCarthy follows:]

Testimony of

James McCarthy

February 22, 1984

Mr. Chairman and Members of the Subcommittee, my name is James McCarthy. I am Professor of Physics at the University of Virginia and I am also the Acting Director of the Continuous Electron Beam Accelerator Facility. I am here this morning to discuss this facility and its importance to the future of nuclear physics. An accelerator with these capabilities has long been a goal of the nuclear science community. This accelerator has the enthusiastic support of nuclear physicists and has been given the highest priority for construction in the recent Long Range Plan for Nuclear Science, a report by the DOE/NSF Nuclear Science Advisory Committee, issued in December 1983.

The nucleus and the fundamental processes that take place within this dense and small region of space are important aspects of our universe. The primary mass of the universe is concentrated in nuclei, and the energy of the universe has its origin in nuclear and gravitational forces. This accelerator will be dedicated to basic research into the studies of the constituents of the nucleus and the forces by which they interact. Even though the accelerator itself will be an extremely large and complex device it will also be a precision instrument. The electron when used to probe the nuclear interior has significant advantages over other types of probes in certain areas. Of primary importance is the electron interacts with the nuclear constituents only through the electromagnetic force and permits a precise and quantitative understanding of nuclear structure, the nuclear constituents and force. By increasing the electron energy one is able to investigate increasingly smaller distances in space. That is one of the reasons why the maximum energy of the electron accelerator plays such an important role in determining the planned experimental program.

Nuclear Physics is on the threshold of new developments which promise to change completely our picture of the nucleus and the theoretical tools which we use to describe the structure of nuclear matter. Our colleagues in particle physics have demonstrated that protons and neutrons are made up of quarks and gluons and have shown that the Quantum Chromodynamics (QCD) provides a fundamental theory for describing the strong interactions. We must now consider that the neutrons and protons are composite particles and use the theoretical framework of QCD if we hope to describe the nucleus from a fundamental point of view. It should also be emphasized that the study of nuclei can also provide new information about QCD which cannot be learned by studying isolated neutrons and protons.

This new picture of nuclei presents nuclear physicists with an enormous challenge, one accompanied with great excitement. The field is taking on a new life which is already beginning to attract new young people into our graduate programs.

In order to study the effects of the composite quark structure of neutrons and protons in normal nuclear matter, it is necessary to have a probe with a spatial resolution of less than 10^{-14} cm, about one tenth the radius of a proton.

As mentioned earlier the electron is an ideal probe since it interacts with the underlying quark constituents through the well-known electromagnetic interaction. This reaction is sufficiently weak that it produces a minimal disturbance of the initial nuclear system. However the relatively weak interaction with the nuclear system means that the event rate is extremely low. This can be compensated for by increasing the beam current which is another important criteria for the new facility. While there exist electron accelerators that have achieved high energy with high current they lack one crucial aspect. The existing electron beams are pulsed in time due to limitations in the accelerator technology with which they were built. The coincidence studies of complex nuclear events requires very high current to achieve an adequate event rate. But unless the precision beam is continuous in time the interesting event will be hidden by a large background rate. The physics criteria then set the requirement for CEBAF:

a) Continuous Electron Beam in Time
b) Energy of at least 4 GeV
c) High Average Beam Current of 200 μA.

During the past several years an active and intense research program has taken place at universities and National Laboratories to develop an accelerator design that would meet these goals. The effort expended by the nuclear physics community on these projects is a clear indication of the strength of the physics program and the urgency for construction of such a facility. The proposals of these research programs were submitted for peer review to the Bromley Panel, a subcommittee of the Nuclear Science Advisory Committee. The SURA organization is honored that its proposal was selected and is dedicated to the successful completion of the project. The Universities and states within SURA have contributed over $1.5 million to this project. The project from its conception to its final acceptance was funded almost entirely from private resources. This is a unique occurrence in the history of large accelerator projects.

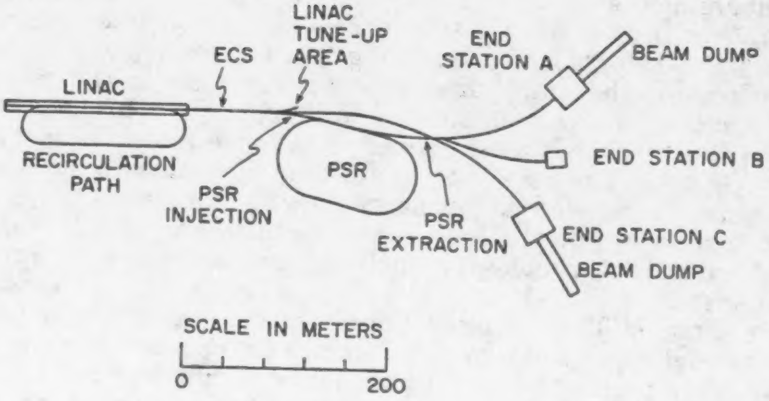
The Linac Pulse Stretcher Ring (LSR) design proposed by SURA combines two existing and well-developed technologies to achieve these unique characteristics: a high intensity pulsed linac similar to SLAC and a storage ring. The technology of both devices are well-understood but to achieve the desired intensity they must approach the current state of the art. A schematic layout of CEBAF is shown in the attached figure. The linac produces a pulse one millionth of a second long one thousand times a second. The storage ring converts the time pulsed beam from the linac into a continuous ring of electrons in space. The electrons are extracted over a period of one thousandth of a second, providing the experimental stations a continuous beam during this period. After the beam has been extracted from the ring the linac is prepared to provide the next pulse to fill the ring and start the entire extraction procedure over again. The design allows a continuous beam to be provided 90% of the time.

The basic facility has two large high intensity experimental stations which will accommodate the major experimental equipment initially planned. A third low intensity experimental station is planned for experiments with photon beams with large acceptance detection systems. All three stations can be used simultaneously, sharing the intensity of the primary electron beam.

The major technical development required for CEBAF is the production of the high powered klystrons needed to drive the linac. These klystrons represent an advance of the state of the art beyond existing klystrons in terms of the average power. We are confident that they can be produced. Several commercial organizations have already given us quotations for their fabrication.

In the event that the klystron development is delayed, existing klystrons can be used. The lower average power provided by such klystrons would reduce the beam intensity by a factor of two but still allow the same maximum energy of 4 GeV to be achieved with a continuous current. The rate at which experiments are completed would be slowed until the higher power tubes are developed, but the quality of the physics program would not be compromised. Other alternative positions, such as lengthening the linac, also exist.

The Linac Pulse Stretcher Ring design offers considerable flexibility: a straightforward expansion allows the extension of the beam energy to 6 GeV. Additional experimental stations can be built and additional storage rings can be added for a variety of nuclear physics and other applications. Space is being reserved to accommodate a number of such multipurpose storage rings in the event the demand arises.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Accelerator Layout

Since the Bromley Panel's recommendation the accelerator design and cost estimates have been refined. SURA is now in a position to begin the staff buildup and to employ an A & E firm for advanced studies of the accelerator and support facilities. These two areas would require the major part of the FY-85 construction funds.

Let me conclude by thanking you for the opportunity to discuss the CEBAF project with you.

Mr. **Fuqua**. I'd like to thank, on behalf of the committee, all the members of the panel this morning; it is a very distinguished one.

Dr. Austin, I believe you referred to the continuous beam electron accelerator facility as being a very high priority. To your knowledge is there any dissent as to that view in the members of the nuclear physics community? Is it sort of a consensus that this is the facility that is most needed to advance research in that area?

Dr. **Austin**. I believe there's a strong consensus. I suppose there are some people who do not agree, but the consensus is very strong that this should be the next major facility, and it will address the most important problems which we see on our frontiers at the moment.

Mr. **Fuqua**. The Bromley Panel—of course, it had a particular charge and spent some months, I don't know how many, in making investigations and inquiries pursuant to that charge. I wonder if you could just briefly summarize the charge and whether or not you feel that the Bromley Panel had a full opportunity to complete its work and to come to confident judgment?

Dr. **Austin**. The charge of the committee, I can read to you briefly. It was: within the context of the NSAC long-range plan for nuclear science of 1979, the discussion of the subcommittee which I had mentioned, the so-called Barnes Panel which outlined the—which laid the requirement for a four GeV beam was, in their opinion, the highest priority; and third, our best scientific judgment, to evaluate the five proposals which were submitted and to examine each of these as a possible component of the overall national program of basic nuclear research and to recommend a facility or combination of facilities which would best meet the U.S. needs for basic nuclear research with electromagnetic probes.

The time scale required in this investigation was, indeed, rather short and because of that reason, required a concentrated effort. I feel, and I believe it's probably a fair recognition of the consensus of the committee that the necessary effort was put in, that a thorough and complete evaluation was done, and that the recommendations of the committee were reasonably determined and well based.

Mr. **Fuqua**. And as I have understood it, the view of the panel was that a facility of this kind represented the larger promise for the most significant research that needs to be done, but that it was also a factor that a facility of this kind would be expandable and would enhance the longer range capabilities of the facility. Would you agree that that potential for future refinement and improvement of the facility exists?

Dr. **Austin**. That is my view. Perhaps Dr. McCarthy could assess that with more technical background.

Mr. **Bateman**. If I might, let me address a question to Dr. Holmgren or Dr. McCarthy as you may prefer.

If funds were provided for additional construction in the fiscal year 1985 budget, are you in a position to use those funds in that timeframe well and to advance the accomplishment of the project?

Dr. **Holmgren**. Yes; we are in a position, we believe, to advance the project. It could advance and start off at a more rapid rate and, I think, have a greater assurance of success of the project, just simply getting it going and on its feet in a hurry.

Mr. **Bateman**. Well, the budget request makes reference to some $5 million in funds for research. I take it that this is to the development of the final detailed plans for the facility. In view of the fact, obviously, the full research detailed plans have not been finalized, there are some, therefore, who might think that you couldn't use construction moneys. Would you speak to that question?

Dr. **Holmgren**. I think Dr. McCarthy should answer that question.

Dr. **McCarthy**. Well, that last point you made was quite correct. The research and development funds are quite crucial for the continual progress of the accelerator. In that, I think both the Department of Energy and we are in complete agreement, that those are very valuable to us. That means that construction of the accelerator proper probably cannot be started until late fiscal year 1986 or 1987; but when those necessary research and development projects are completed. What we are referring to is that many of the technical devices that are being developed under this research and development funding will be coming into the laboratory for testing and acceptance evaluation in late fiscal years 1985 and 1986. The funds which we think we could expeditiously use would be for building up in the existing buildings, the test laboratories, the rehabilitation of those areas which we think will be necessary during fiscal year 1986 for an effective schedule to keep sure that those major prototype items, which are milestone items, meet our present design goals. So it is mainly in the support facility, which is conventional construction primarily, that those funds could be effectively used.

Mr. **Bateman**. Well, with that, Mr. Chairman, I want to defer and give you the opportunity to raise your questions on this distinguished panel.

Mr. **Fuqua**. Thank you very much. I apologize for having to step in and out, but sometimes we have more than one ball in the air at the same time.

Dr. Schiffer, would you relate the recommendations of the DOE and NSF Nuclear Advisory Panel Committee in the December 1983 long-range plan for nuclear science in their priority order?

Dr. **Schiffer**. Their recommendations were in several directions. On facility construction, by December 1983 we had already recommended the electron accelerator as the highest priority of new construction item. That recommendation was transmitted to the Department of Energy in April 1983. So we were looking beyond that. For construction beyond that, we saw this relativistic heavy ion collider as the next major milestone for our field. It's a major scientific opportunity; but it follows after the electron accelerator. The recommendation on operating funds was a crucial one. We felt that with the facility construction going on, with the facilities that we have in hand, that have been completed, and with the resources that we have to utilize those facilities appropriately and to do what we feel is our duty in training new scientists, we need $20 million additional operating money; and to prioritize that with respect to the other two, they are different color things. They are like distinguishing between need for housing and need for food. You need both; you cannot have facilities without building up the operating funds, the capability to utilize them.

Mr. **Fuqua**. How does the DOE and the NSF budget request reflect the panel's priority recommendations, and are there any major differences between the priorities that you recommended and what was recommended in the budget?

Dr. **Schiffer**. I would not say that they are major differences, as I said in my remarks when, I believe, the chairman had to step out. There is a slight effective decrease in the operating funds in DOE for nuclear science. We recommended a $20 million increment overall, and there is no sign of that in the DOE operating funds. I cannot and I do not wish to criticize how the allocations are made within a given sum of money, but I do have to point out that that is a very painful budget for the ongoing research programs in our field.

Mr. **Fuqua**. Well, in the order of priority, what were the recommendations for the incremental fundings for the fiscal year 1985 budget for DOE and NSF and how they should be spent?

Dr. **Schiffer**. Well, I can address our recommendations on the incremental $20 million operating funds in the two agencies. We saw them as being used for utilization of facilities, many of which are now operating at near 50-percent level—not so much in terms of operating hours, which is a measure our high energy colleagues use, but also in terms of the level and quality of operation; instrumentation and control systems have long been neglected because budgets have been very tight. Often the right personnel have been cut back to the point where it is really bare bones, and it's not possible to provide the services to users, university users in particular, that they should have to make the utilization of those facilities appropriate. Small increments in money can make a large difference.

Then, in the educational field we felt that there are students not being trained. Students are being turned away from a career in science, in nuclear science, because the funds are not available to give them training.

There is instrumentation. The leadership that the United States had in nuclear instrumentation has fallen behind. European laboratories are often doing much better, much grander things. We just have to revitalize instrumentation in this country for the benefit of our science, but also for much broader benefits that develop from it.

And finally, we had the recommendation of a small increment to make technical personnel available to university user groups. At larger facilities, more and more universities are becoming users at facilities away from their home institutions. We badly felt that we needed some moneys to allow them to get such technical support.

These were the major ingredients of this $20 million increment in operating and equipment money.

Mr. **Fuqua**. Now, let me ask you a couple of questions.

Dr. **Schiffer**. Yes, sir.

Mr. **Fuqua**. Suppose that—because there's approximately a little over 16-percent increase in this budget—suppose that this committee or the Congress decided to reduce the funding by, say, about 10 percent. Where would your priorities be then with DOE and with NSF in these areas?

Dr. **Schiffer**. That is a very difficult question to contemplate, and we would have to rethink our national program. I don't know that we could accommodate a 10-percent cut without shutting down some major facilities, but I think the agencies would have to look at that——

Mr. **Fuqua**. What about the operating time of the facilities? Would that be affected?

Dr. **Schiffer**. It might well mean that some facilities would have to be shut down, so the operating times would go to zero.

Mr. **Fuqua**. Mr. Austin, what would be some—or what was the specific charge, I guess I should say, to the technical subpanel? What criteria did you use in your decisionmaking process and what weights did you give to there criteria versus another type?

Dr. **Austin**. The subpanel was charged, basically, to make a detailed examination of the technical and accelerator aspects of these proposals and also to assess the research and development that had been done, and what remained to be done. Further detail which this technical subpanel took care of was to attempt to put the various proposals on an equal footing as to funding by making adjustments in the cost estimates associated with various aspects of construction so that we could compare apples with apples to the largest extent possible.

The criteria—there was no specific weighting of criteria that was panelwide. It was the decision of the panel that the best scientific evaluation was likely to result if each individual member of the panel assessed the criteria according to his own best judgment, and this is what was done. Some of the important criteria were the importance of the accessible physics, since we had received proposals at a variety of maximum energies; feasability of the project; the educational potential. There was a list of approximately 20, and I don't think it's worthwhile to go through all of them unless you ask me to—but the basic statement is that there were no committeewide weightings, individual weightings. It was by the best judgment of each member.

Mr. **Fuqua**. What were the bases of the cost adjustments that were made to each of the Argonne proposal and the SURA proposal?

Dr. **Austin**. The fundamental basis, as I stated, was an attempt to put these proposals on an equal footing in the best judgment of the members of the technical subpanel. These were basically, an attempt to assess the research and development that had been done and that which remained to be done, and, in the judgment of the subpanel, add amounts to the different proposals to reflect the judgment of that item.

Second, there was assessment of the risk of the individual proposals and of the techniques involved and hence the possible contingencies that might need to cover additional costs associated with these risks.

And finally, there was an attempt to estimate the costs to equip each of the facilities with a complex of experimental equipment which would meet the needs for our national program.

These are the three major items in which adjustments were made. I cannot comment in more detail at this point why *x* amount of dollars went into *x* category, but those were the general criteria that we used.

Mr. **Fuqua**. Dr. Holmgren, you—or Dr. McCarthy, how much money has the Commonwealth and the University of Virginia contributed to the SURA proposal?

Mr. **Holmgren**. It's the—all the universities in the SURA organization have contributed in various ways. The total funds in terms of faculty efforts that have gone toward this are in excess of $1 million, probably close to one and a half million dollars.

Mr. **Fuqua**. That's a total cost, not broken down by States or——

Dr. **Holmgren**. That's a total cost, the total contributions that have been made to date.

Mr. **Fuqua**. Maybe Dr. McCarthy—do you recall how much Virginia has put up?

Dr. **McCarthy**. Well, the Commonwealth has contributed the majority of that support. I would say that that approaches half of that, approximately three quarters of a million from the Commonwealth.

Mr. **Fuqua**. That includes the university?

Dr. **McCarthy**. That includes the university in direct State contributions. Our latest technical refinements in costs are being carried by a $200,000 support from the Commonwealth.

I should mention that we expect—hopefully, by July 1—$1 million will be available for senior staff positions from the Commonwealth of Virginia.

Mr. **Fuqua**. Dr. Holmgren, you had noted in your statement that there would be a permanent director appointed by July of this year, and a number of senior positions had been identified. When did you plan to have the other four Commonwealth professorships filled with senior accelerator physicists?

Dr. **Holmgren**. What I said was, we hope to have the permanent director in place. We hope to have the permanent director picked within a matter of a month or two, and that we also will start filling some of those positions almost immediately, or start looking for candidates to fill those positions almost immediately. Our National Advisory Board has suggested that we reserve, say, two of those positions for when the director actually comes on board so he has a chance of filling spots with somebody——

Mr. **Fuqua**. He'd be filling them himself?

Dr. **Holmgren** [continuing]. But that we should start filling the other ones as quickly as possible.

Mr. **Fuqua**. Well, in the initial proposal that was submitted to DOE and NSF in 1980, the project's cost was estimated to be under $100 million; and the Bromley Panel concluded that with additional contingencies in R&D and equipment, costs might be under $150 million. And now, in the budget submission that DOE has submitted to us, they range now from $200 million to $225 million. What's the reason for the increases and what escalation costs are we assured will not happen again, from the figures submitted by DOE?

Dr. **McCarthy**. Mr. Chairman, what you say is correct; the Bromley Panel's recommendations for added contingencies, those have been accepted as reasonable adjustments for our proposal, for where we stand.

Let me state that the base cost at $150 million is dependent upon work done primarily during fiscal year 1982; so that represents fiscal year 1982 dollars. A complete cost evaluation had been done by January, fiscal year 1984. As to be expected, there has been escalation in the base costs of approximately 10 to 15 percent in certain items. In some items, initial construction has not gone up that much. The major difference that you see in the $150 million base cost is that that is an escalated figure over the 5½ year construction period; so all the obligation and expenditures have been multiplied by a Department of Energy multiplicity factor. For example, if any funds are expended in fiscal year 1990, you have to multiply by 1.65. So I would say that $220 to $225 million is consistent with the base cost of $150 million in fiscal year 1982 dollars.

Mr. **FUQUA**. So, in fiscal year 1985 dollars, then, you think that's a rather firm figure, between $220 million—up to $225 million?

Dr. **MCCARTHY**. It's firm in the sense that if the construction schedule is maintained, which I would say at this stage means that the facility would be in full-scale operation in fiscal year 1990, then that is a reasonable figure. Any delays would push that figure higher.

Dr. **HOLMGREN**. The $225 million is the escalated figure at the time the construction actually takes place. It's not in fiscal year 1985 dollars.

Mr. **FUQUA**. When will construction take place, in 1986?

Dr. **MCCARTHY**. The construction is a 5-year period. Assuming we start in fiscal year 1985 with the present $2 million and we have a construction schedule laid out which goes to $31 million in fiscal year 1986, and continuing funding with, hopefully, all obligations finished by fiscal year 1988, final construction——

Mr. **FUQUA**. So that's the total escalated cost? So it shouldn't be over that and you should—not come back in here 2 years from now and say, well, we need $350 million?

Dr. **MCCARTHY**. No. That is the escalated, actual year cost.

Mr. **FUQUA**. Well, that's good. And do you anticipate any show stoppers in the construction, particularly the equipment?

Dr. **MCCARTHY**. There are several designed klystrons and a variety of technical components that we need, but none of those are what you call in a "hard failure" mode. And that was also an important criteria for the Bromley panel decision, that those devices which were pushing the state-of-the-art, that we always have a fallback position; so we will set time goals, that this device has to be operational by then, or else we have to go back to a fallback position. So at the moment, we have not identified any.

Mr. **FUQUA**. So you anticipate your operational schedule is to begin in fiscal year 1990?

Dr. **MCCARTHY**. That's the present plan that the linear accelerator is based upon operation, in fiscal year 1990.

Mr. **FUQUA**. In what part of fiscal year 1990?

Dr. **MCCARTHY**. It is difficult at this stage——

Mr. **FUQUA**. It gives you 12 months' flexibility. So don't pin yourself down. [General laughter.]

Dr. **MCCARTHY**. I would say it's the latter part.

Mr. **FUQUA**. That's all, Mr. Chairman——

Mr. **BATEMAN**. Mr. Chairman, I might, if I could add this comment, to suggest that if they could get some construction money for fiscal year 1985 they'd be able to finish faster and bring it in at lesser cost.

Mr. **Fuqua**. I understand.

Well, thank you gentlemen very much for——

Mr. **Bateman**. Mr. Chairman, please, if I might, I was asked by Mr. Carney, who had to leave, if I would seek unanimous consent for his statement to be placed in the record.

Mr. **Fuqua**. Yes, we'll place the statement in the record.

Well, thank you, gentlemen, very much for being here today and you have aided us greatly in our deliberations and understanding of a very important subject, and particularly, a very important new project; and we wish you well with it. Thank you very much.

[The opening statement of Mr. Carney follows:]

OPENING STATEMENT OF THE

HON. WILLIAM CARNEY (R-N.Y.)

EDA SUBCOMMITTEE HEARING ON

FY 1985 DOE AUTHORIZATION FOR

HIGH ENERGY AND NUCLEAR PHYSICS

FEBRUARY 22, 1984

THANK YOU, MR. CHAIRMAN, FOR ALLOWING ME TO TAKE A FEW MOMENTS TO WELCOME DR. TRIVELPIECE AND OUR OTHER DISTINGUISHED WITNESSES AND PANELISTS.

IT IS A PLEASURE HAVING ALL OF YOU HERE TODAY TO BEGIN THIS FIRST ROUND OF LOOKING AT THE ENERGY RESEARCH AND DEVELOPMENT PORTION OF THE DEPARTMENT OF ENERGY'S BUDGET FOR FY 1985; AND, AT THE SAME TIME, I WANT TO COMMEND THE ENERGY RESEARCH DIRECTOR AND HIS STAFF FOR THEIR FINE WORK.

EXAMINATION OF THE BUDGET REQUESTS FOR HIGH ENERGY AND NUCLEAR PHYSICS PROGRAMS BOTH SHOWS PROMISE FOR THE FUTURE OF THESE EXCITING RESEARCH ENDEAVORS IN THE UNITED STATES AND ILLUSTRATES THE TREMENDOUS IMPORTANCE BOTH THE CONGRESS AND THE ADMINISTRATION PLACE IN THESE SCIENCE PROGRAMS.

I BELIEVE OUR SUBCOMMITTEE, AND OUR FULL PANEL, HAVE DEMONSTRATED OUR WILLINGNESS TO SUPPORT THESE PROGRAMS AND TO ESTABLISH THE FRAMEWORK IN WHICH THE CONGRESS AND THE ADMINISTRATION CAN WORK TOGETHER IN THEIR DEVELOPMENT AND IMPLEMENTATION.

I WOULD SINCERELY ENCOURAGE THOSE OF US HERE TODAY TO CONTINUE IN THIS SHARED GOAL TO MAINTAIN AMERICAN PREEMINENCE IN THESE VITAL RESEARCH PROGRAMS AND I LOOK FORWARD TO THIS MORNING'S PRESENTATIONS AS TO HOW WE MIGHT BEST ACHIEVE THAT END.

THANK YOU, MR. CHAIRMAN.

The subcommittee will stand adjourned until tomorrow morning at 9:30.

[Whereupon, at 12:23 p.m., the subcommittee recessed, to reconvene at 9:30 a.m. Thursday, February 23, 1984.]

APPENDIX I

QUESTIONS AND ANSWERS FOR THE RECORD

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DON FUQUA (Fla.), Chairman

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RICHARD L. OTTINGER, N.Y.
TOM HARKIN, IOWA
MARILYN LLOYD, TENN.
DOUG WALGREN, PA.
DAN GLICKMAN, KANS.
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TOM LEWIS, FLA.

HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Maury Tigner, Director of Operations
Wilson Synchrotron Laboratory
Cornell University
Ithaca, New York 14583

Dear Dr. Tigner:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

Don Fuqua

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. TIGNER

1. What is the expected outcome of the SSC Reference Designs study? How will you know if you have succeeded or failed?
2. What information or input does the SSC Reference Designs study provide for the Phase I R&D plan?
3. Is there a separate Phase I R&D planning activity underway, and if so, when will such a plan be available?
4. How critical is the 20-TeV energy specification to the SSC's reference design ?
5. What additional possibilities exist for SSC cost reduction?
6. How much is it expected to cost to bring each of the alternative magnet designs to a go/no-go decision point?
7. You have mentioned items included in the Reference Designs Study. What additional items are not being considered? For example, is the study considering detectors, operations R&D, detailed staffing plans, and so forth?

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COMMITTEE ON SCIENCE
AND TECHNOLOGY

March 12, 1984

Hon. Don Fuqua, Chairman
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman Fuqua:

Herein are the answers to your written questions about my testimony before you on February 22, 1984. Your questions are very much to the point and I thank you for the opportunity of addressing them for the public record.

Yours sincerely,

Maury Tigner

1) What is the expected outcome of the SSC Reference Designs Study? How will you know if you have succeeded or failed?

The outcome will be a more detailed assessment of technical and economic feasibility than heretofore available. If successful, the study report will contain a well defined list of R/D objectives which can be used to design a goal oriented R/D program leading to a detailed SSC proposal in approximately three years. Such a program would be characterized by a rapid narrowing of economically attractive technical options and subsequent intensive focus on development and reliability engineering of the chosen option. If such a list of objectives cannot be defined or are patently unrealistic, we shall have failed.

2) What information or input does the SSC Reference Designs Study provide for the Phase I R/D plan?

The RDS will provide the objectives to be addressed by the plan.

3) Is there a separate Phase I R/D Planning Activity underway and, if so, when will such a plan be available?

Currently each of several National Laboratories (BNL, FNAL, LBL), Consortia of universities (Texas A & M, Rice, U. of Houston, U. of Texas at Austin) and a single university, Cornell University, are formulating plans loosely guided by the DOE through the HEPAP sub-panel on AARD. To the best of my knowledge, these plans are now being reviewed through the normal agency mechanisms. The DOE has been advised through HEPAP to create a mechanism for more coordinated guidance of this R/D though no such mechanism is in operation at this time.

4) How critical is the 20 TeV energy specification to the SSC's reference design?

In asking this I assume you are asking how important is it to have 20 TeV beams available to U.S. particle physicists for exploration beyond frontiers that will be reached by accelerators now under construction.

While not as precise as the calculations which predicted the energy scale of the Wand Z bosons recently discovered at CERN, theorists predict that striking new phenomena will be manifest at elementary collision energies of 1 to 2 TeV. These may involve production of the so-called Higgs particle or some other manifestation of the mechanism responsible for the symmetry breaking observed at current frontier energies. Since the protons to be collided in the SSC are composite particles with the elementary particles within sharing the total energy, the proton beam energy must be approximately 10 times the elementary collision energy needed. With this in mind, physicists have targeted 20 TeV as an appropriate energy goal for the SSC.

5) What additional possibilities exist for SSC cost reduction?

In addition to economic optimization of the accelerator itself, which will be the objective of Phase I R/D, it is clear that timely execution of the construction plan to be produced in Phase I and choice of a favorable site, several of which exist in the U.S., will be of great help in controlling and reducing cost.

6) How much is it expected to cost to bring each of the alternative magnet designs to a go/no-go decision point?

I would not want to prejudge the results of R/D planning now in progress. However, I can tell you that in presentations to the HEPAP sub-panel on AARD, it was estimated that completion of Phase I should be expected to cost about 150 million dollars. Envisioned in that plan was a narrowing of options to one in a period of about 18 months with concentration on the one option for the remainder of the study.

7) You have mentioned items included in the Reference Designs Study. What additional items are not being considered? For example, is the study considering detectors, operations R/D, detailed staffing plans, and so forth?

Specifically excluded from the Reference Designs Study scope are possible technical optional features such as fixed target operation, acceleration of polarized beams and provision of an electron accelerator for the study of electron proton collisions. Additionally excluded in our directive from the Directors were detector costs, preconstruction R/D and a detailed study of operations costs. For purposes of sizing the facility we have made some assessment of staffing needs. An estimate of operations costs can be made from these numbers together with the expected utility consumption which will be calculated in the Reference Design Report. With regard to detector designs which will lead to cost estimates, there is already considerable ad hoc activity. As you know, a nationally representative group of about 200 physicists, the "PSSC" (Physics with the SSC), has been meeting monthly to discuss these problems. In June and July there will be a DPF meeting of 3 weeks duration at Snowmass, CO for intensive discussions. From these types of activities, I believe we will have a rather good idea of detector needs well before a detailed construction proposal for the accelerator is finished.

DON FUQUA (Fla.), Chairman

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February 28, 1984

Dr. Leon M. Lederman, Director
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

Dear Dr. ~~Lederman~~ Leon

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

Don

DON FUQUA
Chairman

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attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. LEDERMAN

1. Is there any validity to or documentation for the claim that high energy physics is an economic benefit to the U.S. due to its technological spin-offs alone?

2. What are other benefits to the U.S. of a strong high energy physics programs?

3. Do the relative cost-benefits of high-energy physics warrant the current, or larger, or a smaller level of funding when compared with other fields of science? Why?

4. What is the detector situation at Fermilab? Are there going to be adequate detection capabilities available when TeV I and TeV II are operating at their design specs?

5. What are Fermilab's long-range plans? Do you see the current machines carrying you forward into the next century?

EDA

Fermilab

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Directors Office

March 9, 1984

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MAR 1 _ 1984
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Mr. Don Fuqua
Chairman
U.S. House of Representatives
Committee on Science & Technology
Suite 2321 Rayburn House Office Building
Washington, DC 20515

Dear Mr. ~~Fuqua~~ Don:

Enclosed are the responses to the questions posed in your recent letter.

Sincerely,

Leon

Leon M. Lederman

Enclosures
Viewpoint
Response to Mr. Fuqua's letter

L. M. Lederman
March 9, 1984

1. Is there any validity to or documentation for the claim that high energy physics is an economic benefit to the U.S. due to its technological spin-offs alone?

In 1982, I did a study of this problem for an NSF Workshop (The Role of Basic Research in Science & Technology NSF/PRA-8303). I enclose this long paper and present a brief synopsis in answer to your question. Experimentation at the frontier requires the invention of novel instruments and techniques which are later found to have applications in industry, creating goods and services which add directly to the GNP and to other research areas which in turn have direct and indirect effects on technology. My study was anecdotal but led to the conclusion that if we average over the past twenty or so years, the taxes paid to the Treasury return a substantial fraction of the cost of the basic research. There is additional pay back, harder to quantify, in the enhanced quality of life induced by the new products. The accelerator that destroys a tumor generates profits for the manufacturer and the doctor but it also prolongs a productive life. Spin-offs also create new possibilities for basic research often in completely different fields. For example, high energy physics of the early 1900's yielded much information on X-rays - these created the field of crystallography and enabled the breakthrough in molecular biology which is now the basis of a multi-billion dollar industrial biotechnology. Finally, an important product of high energy physics is the trained scientist. About half of the Ph.D.'s in high energy physics (about 80 Ph.D.'s/year) leave the field of basic research and go into industry, teaching, government and defense laboratories.

In the following table I list some of the financial activity which was generated by inventions in the high energy laboratories and for which industry spokesmen were able to supply me with estimates. References to some more systematic studies carried out by professional economists is also appended. These are not specialized to high energy physics. Such a study was carried out at our European counterpart at CERN (see Reference below), which concluded that, from 1952 to 1978, CERN produced a net "utility" of $2.4 Billion in economic activity generated by firms who developed new products out of CERN interactions.

TABLE I

Crude Estimates of Economic
Value of H.E.P. 1950 - 1980

Item	Comment	Estimated Economic Activity
Recruiting young people into science	About 80 Ph.D's/year trained in HEP enter other fields, largely applied sciences. (1955 - 1980)	$0.5B/year (over 25 years)

NMR (SC magnets)	Medical Diagnostic Tool Based on nuclear magnetism and superconducting magnets	$1.0B/year Projected for 1985 (WSJ 10/5/83)
Electron Linacs for Radiograophy	Inspection of welds	$0.1B/year
Radioisotope Production	Cyclotron	$0.2B/year
Radiation Processing of Food, Plastics, thickness gauges	Electron Linacs	$1.4B/year
Medical Accelerators	Cancer treatment: Electron Linacs, cyclotrons protons, neutrons, gammas	$1.0B/year
Ion Implanting Accelerators	Implanters produce alloys with infinitesimal quantities of the additive metal. Semiconductor Industry	Semi-conductor Industry Activity $10B/year, Ion Implanters $400M
Oil well Logging	Accelerators are lowered into wells for chemical analysis of materials	$0.9B
Synchrotron Radiation using electron storage rings	Surfaces, Catalytic Chemistry lithography, tomography, etc.	?
Sodium Iodide	Particle Detectors developed by Hofstadter are now used in a wide variety of industrial and medical devices.	$0.08B/year
CAT Scanning	Computer aided Tomography invention of A. Cormack (Nobel Prize), High Energy physicist. Uses HEP techniques	$0.8B/year
Solar Energy Concentrator	Developed from Cerenkov counters used in H.E.P.	$0.05B/year
	GRAND TOTAL More than	$5 B/year
	Taxes Paid: More than	$1 B/year
Total Cost of HEP	(1983)	.5B/year

TABLE II
Activities which will provide spin-off in the Future

Item	
1. Superconductivity	Potential Application of Developments made at Fermilab, BNL: 1. MHD techniques for power generation 2. Tokamak fusion energy devices 3. Compact Superconducting alternatives, under construction at GE, Westinghouse 4. Large MG sets under study by GE and Garrett Corp. 5. NMR medical scanners 6. SC transmission lines 7. SC levitated trains (MAGLEV) 8. High Gradient Magnetic Separation (HGMS) -

Potential for tens of billions of dollars of applications. Not all will follow directly from Fermilab efforts but the pioneering of massive SC systems, quality assurance, controls, etc., is a strong contribution.

2. Cryogenics	Refrigeration machinery supplied by vendors has been substantially improved by Fermilab-vendor discussions.
3. Theoretical Physics	Many of the calculational techniques developed for high energy physics are being used in polymer chemistry, oil exploration, parallel processing technology, theory of fluids and of turbulent flow.
4. Ultimate technology transfer	HEP Scientists and Engineers often form their own companies: Lecroy Research System Inc, Digital Pathways, Kinetic Systems, Omnibyte, Inc., NYCB Real Time Computing, Inc. These small companies generate business at the level of $50M/year.
5. Parallel Processing & Data Busing	CAMAC, FASTBUS, Electronic Standards, New Computer Architectures. These are filtering into industrial and provide new approaches to super computers.

References

CERN Economic Study: H. Schmeid CERN 75-5 (June 1975).

2. What are other benefits to the U.S. of a strong high energy physics program?

Many of my colleagues will tell you that the strongest way HEP benefits our society is by the enhancement of our culture. To understand the world we live in is a natural human ambition; it contributes to human dignity and to an appreciation for humanity as a part of nature. But there are more concrete goals:

1. There is the recruiting - although cheap energy sources or greenhouse effect may be a pressing technological problem, the young mind will be drawn to science by black holes, antimatter, neutrinos. Once entrapped many go on to useful things (80 PH.D.'s year leave the field - they are in great demand [Bell Labs advertizes for HEP physicists]).

2. The major contribution is in providing the basis for technology. This has been the traditional role. We hail from a long line of intellectual heroes - the HEP'ers of the past - Newton, Maxwell, Einstein, Rutherford, Fermi who have changed the world. The same curiosity, drive and attention to the most fundamental problems in physics motivates HEP. The technological problems of the 21st Century are enormous as an increasingly demanding population competes for dwindling natural resources. It is not clear that we know eough about nature to provide the needed technology.

3. Finally, HEP is an intensely international activity. Scientists from over 23 countries have worked at Fermilab over the past ten years. In their ambitious modernization program the PRC listed HEP as one of four major fields in which they intended to invest. High Energy physicists have earned more Nobel Prizes than all other sciences. In this context, international prestige becomes a very crucial element.

3. Do the relative cost-benefits of high-energy physics warrant the current, or larger, or a smaller level of funding when compared with other fields of science? Why?

I really cannot address the status and opportunities in other fields of science. One needs to be critical and subject all sciences to the criteria of viability. Are young people attracted? Can they excite the general public? Do they win Nobel Prizes? I have noticed that HEP is generally considered a very aggressive field - I believe we have been responsibly aggressive - we have pushed for the facilities we need to advance the subject but we have closed viable but-not-good-enough facilities CEA, PPA, Argonne, LBL, Cosmotron, etc., in order to obtain the funding. Have other sciences suffered? From 1967 to

1984, I noted that the ratio of HEP to all basic research dropped from 11% to 8% in spite of the construction of Fermilab, PEP, Tevatron and SLC. This decrease is presumably due to the increase in number and in cost of other sciences which compete. I would more easily say that the scientific opportunities in HEP are, in 1985, almost matched to the funding - the deficit being about 5%. A serious comparison of the balance between sciences is probably possible but would be very difficult and certainly could not be done without much study.

4. What is the detector situation at Fermilab? Are there going to be adequate detection capabilities available when TeV I and TeV II are operating at their design specs?

This is the critical point in the exploitation of the TEVATRON. We have one excellent, all purpose, complex detector for TeV I. This is being constructed to observe $\bar{p}$ x p (TeV I) 2000 GeV collisions. It is my feeling and I was convinced by many (PAC, DOE, HEPAP) that one detector is not enough and needs to be complemented considering the enormous capability of TeV I. We have internally approved a second detector, DO, proposed by about seventy physicists from Stony Brook, BNL, and eight other institutions. This detector will cost somewhat under $30M over the period 1985-1988. At this stage we do not have equipment funds to construct this detector. We have a program of all new, 1000 GeV, (TeV II) experiments, stretching out to 1987 and which requires a great deal of equipment money. This is the problem I mentioned in my statement. For Fermilab, the combined shortfall in FY 1985 is $8M in equipment funds. If we are to exploit the TEVATRON from '84 → '94, say, with the main competitive thrust in '86-'89 we would need this pulse in '85-'86. I do not know what is in store in FY 86.

5. What are Fermilab's long-range plans? Do you see the current machines carrying you forward into the next century?

Long Range? No - TEVATRON plays out in '94-'95. It is very hard to say we will not think of something new but if I had to guess, I'd say that Fermilab will close in favor of the SSC. This was the opinion of the senior staff several years ago when we decided to push the SSC concept (I named it Desertron). We naturally see benefits to institutional longevity, especially an institution as successful and vibrant as Fermilab - but not at the expense of attacking the most fundamental problems of nature. Therefore, unless there is an unforeseeable and brilliant invention, we do not really see operating the present Fermilab machines much beyond mid-1995.

Revised April 15, 1982
Leon M. Lederman

For NSF Workshop: Basic Research and Development
For The Advancement of Energy Science and Technology

VIEWPOINT FROM FUNDAMENTAL SCIENCE

L. M. Lederman

FERMILAB
Batavia, Illinois

February, 1982

Abstract

This paper was instigated by an invitation to participate in a workshop, "Basic Research for the Advancement of Energy Science and Technology." I was told that the purpose of the workshop is to examine the role of basic research in the advancement of energy-related science and technology, as well as broader national interests, including the overall U.S. scientific enterprise.

Guided by my own experience, I chose to separate out and focus upon the field of high energy particle physics and other sciences equally remote from technological applications. The issue is how does this kind of research impact on national needs including energy science and technology. Time scales for such influence may be roughly divided into three intervals, the longest, I identified with cultural effects, the next longest being direct application of the research and the shortest time being indirect or spinoff effects.

If my numbers are correct, this kind of research is essentially free to society, paying its costs in the short term yet providing science and societv a profound cultural heritage in the long term. I close by urging a quantitative study of the economic utility of very basic research in order to form the basis for a rational science policy.

I. Introduction

The role of basic research in the advancement of energy-related science and technology is being examined in order to improve the strategy of long range science policy planning. One sensible approach is to look at the needs of the nation and identify the research areas which are relevant. This implies a concept of relevant basic research. The definition of basic research spans a very broad range of activities and motivations. In this paper I will treat that portion of the continuum which is found at one extreme end - lets call it Very Basic Research or VBR. It is the end most remote from application, not necessarily in time but certainly in the expectation of payoff or "risk" factor. VBR is the traditional activity (a long time ago it was called "science") designed to satisfy curiosity and ego; it addresses problems at the frontier of knowledge.[1] The doing of VBR is wholly uncontaminated by impure thoughts of usefulness or application. One engages in VBR out of a sense of joy in enhancing the culture of man, out of awe at the heritage handed down by generations of masters and out of a need to publish first and become famous.

As a vehicle for discussion I will lean heavily on my own discipline which would seem to be as remote from useful application as one can get, the study of high energy particle physics. This subject seeks for an understanding of the nature of the most fundamental particles and the forces by means of which they interact and bind together to make the things of the world in their infinite variety. Tests of this understanding involve predicting the conditions at the beginnings of the universe and predictions as to its eventual evolution. In this sense, in its very recent developments, the subject merges with cosmology and astro-physics, especially in the attempts to track the first incredibly minute fractions of a second in the life of the universe.[2]

The thrust in this paper is designed to influence policy towards a much more critical examination of the health of basic research for the sake of our future. In taking this assignment I am painfully aware that the interaction of science and policy - the "science of science" has had the attention of generations of scholars from Francis Bacon to Herman Kahn. I bring no new scholarship. My insights are derived from experience in doing irrelevant research, in teaching and recently, in learning how to administer a large VBR laboratory.

The case for very basic research in advancing energy-related science and technology as well as advancing the overall U.S. scientific and technological enterprise traditionally rests on history. In Newton's time, the elementary objects were falling apples and orbiting moons. The unification of these phenomena was the first in a series of syntheses which today threatens to furnish us with a

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complete understanding of the strong, weak and electromagnetic forces. In between, VBR claims the adherence of those scientists who reduced heat and thermodynamics to mechanics e.g. Bernoulli, Joule, Kelvin, Clausius, Boltzmann and Maxwell; those who established the laws of electricity, magnetism and physical optics such as Cavendish, Oersted, Ampere, Faraday, Maxwell and Hertz. The atomic age was ushered in by Lenard, Lorentz, Thomson, Rutherford, Bohr and Einstein. Nuclear physics began with Bequerel, Curie, Joliot, Rutherford, Chadwick and Lawrence among others. The quantum era found VBR adherents including Schrodinger, Heisenberg, Pauli and Dirac preparing the way for the modern quantum field theorists like Fermi, Lamb, Schwinger, Feynman and Gell-Mann. This is a very incomplete listing of the intellectual heroes who have given us our heritage.

It is hardly controversial to claim that the scientific underpinnings of all of modern science and technology rests on the achievements of VBR up through the 1940's. It may not even require the credentials of historical scholarship to establish that each major synthesis from Newton to Feynman has had a profound effect on the state of science and technology as it exists today.

Before proceeding further, one should acknowledge the complete synergy of basic research and technology. It is accepted as totally obvious that basic research, VBR, rests heavily on the available technology. It is for this reason that progress in science and technology is highly non-linear, the slope of progress, continually increasing with time. It is in fact the dependency of modern basic research on a large and costly technological support that creates the current need for wise science policy. VBR is in general expensive and is absolutely dependent on national science policy. There is also a symmetrical dependency - national policy must recognize the increasing need for new understandings to cope with technologically driven societal crises of which energy sufficiency is only one in current fashion.[3] Society has long since passed the point of no return and must be fully committed to a faith - a belief in the ultimate benefits of rationality. We are not really debating the principle of societal support of basic research, we are haggling over the price.

It is in this historical context that I would like to discuss the relevance of VBR to the health of science, technology and the general welfare, including energy-related capability in the coming years. I will do this under three headings: Culture, Direct Effects and Indirect Effects.

There is a continuity in the way each of these activities returns benefits to society. Culture, the most important impact, takes the longest and most circuitous route. It is therefore the least obvious. Direct and Indirect effects of VBR take increasingly shorter and more obvious routes. In the conclusions I will strongly suggest the need for a thorough study of some of the issues that require sharpening if these considerations are to offer any guide for policy.

II. Cultural Matters

Many colleagues are astonishingly shy about raising the cultural issue in full view of policy makers. Part of the reason is that the issues are philosophical and hence cannot possibly hold attention or compete in times of socio-political-economic crisis. It is difficult to establish that fraction of the GNP which can be identified with the cultural value of science. It may also be true that many scientists who should know better tend to forget how they got here and it may well be that policy makers are to be credited with a much greater sensitivity and appreciation of this issue. In this regard I recommend reading the Hearings before the Joint Committee on Atomic Energy, especially in the years 1965-1973.

It is my conviction, formed from 30 years of teaching and practising science and from involvement in the suburbs of policy making, that this most important issue cannot be overemphasized. To address the title of this workshop, basic scientific research is not for energy science and technology. It is for culture. It is for continuing to refine our scientific world view. For this it deserves the support of society.[4] Society must care about science in the same way that it must care about its other creative intellectual activities as art, music and literature. The close analogy of the intellectual processes in science and art has been drawn in many places.[5] There is however, the valuable distinction that art, music and literature have a significant base of support from the public and from private philanthropy.

Having said these things I hasten to acknowledge that society may not yet be ready to allocate to each of its cultural activities the required resources. In the interim, adherents of VBR, science, bend to other arguments which we will detail below. However, even if we make the assumption that high energy physics and extra-galactic astronomy will never have any direct, utilitarian applications, we will insist that they effectively influence the advance of useful science in at least two ways. One has to do with recruiting. The other has to do with setting standards of rigor and quality, and with maintaining the esprit of the scientific community.

As already stated, studying apparently remote and exotic regions of inner and outer space is an example of the kind of rational behavior our society is committed to - we want to do as well as we reasonably can in these matters. It reinforces our behavioral style, it is part of our faith that it is good to know these things. And we keep discovering surprising connections - organic molecules in space and clouds of neutrinos that may weight something. These remind us of the unity of science and are therefore applicable at home.

If the cultural value of these sciences is not given its required weight in long range science policy planning, we will have a second rate enterprise - innovation and progress will slow and the carefully debated issues of "how much solar," "what pace fusion," "more into surface physics" will not, in the long run, amount to very much. To appreciate the power of the cultural drive, one must spend enough years with undergraduates or, even more dramatically, with the high school students such as those who flood my laboratory each Saturday morning. It is out of these culturally agitated young people that the genius will come to solve our many problems in unexpected ways. No long range strategy devised in Washington conference rooms will work without the flux of new entrants into the field and without the intellectual heroes that draw them.

The earliest drive towards explanations of how things work was a cultural one. And it is the cultural appeal which has attracted the best minds into science. Whereas the guarantee of an economic and clean source of energy may be the most crucial scientific problem of our day, the bright high school student will more often be drawn to science by the puzzle of neutrino mass, antimatter and the big bang theory of creation. Not only is pure science a recruiting factor but its success sets standards and reaffirms confidence among workers throughout the spectrum of science. Victor Weisskopf[6] calls this the intrinsic value of science:

> "Basic science is a most powerful element in the philosophy of our time, ... and leads to a more intimate relation between man and the things in nature. It creates an awareness... of connections between phenomena, ... how everything depends on everything - of how the universe, the atom, and the phenomena of life are one and co-exist."

Weisskopf goes on to speak of the community of scientists formed by the culture of the subject:

> "The most rewarding moments in the life of a scientist are certainly those when he himself has found something new. But there are also those moments when he is about to realize some new essential insight made by others, by reading a paper or by listening to a presentation. There is this peculiar joy of insight, of recognizing some deeper coherence in the fabric of nature. These moments of recognition may be rare but they are an essential element in forming the scientific community."

An interesting anecdotal illustration of the cultural drive involves that quintessential technological breakthrough of modern times - the transistor. In this example, an element in the motivation was the importance of finding active solid state circuit elements. This 1947 discovery owed much to parallel technological developments but fundamental to the discovery was the prior application of the quantum mechanical explanation of the band structure in semiconductors in 1931 by A. H. Wilson. Walter Brattain writes:[7]

> "The transistor came about because fundamental knowledge had developed to a stage where human minds could understand phenomena that had been observed for a long time. In the case of a device with such important consequences to technology, it is noteworthy that a breakthrough came from work dedicated to the understanding of fundamental physical phenomena, rather than the cut-and-try method of producing a useful device."

The effort to convey the importance of the cultural content of scientific research to policy and budget makers deserves serious scholarship. There is much to explore. Sensitivity to the cultural value of science leads to considerations of other aspects of culture in society and to a more harmonious coexistence of science in society. Recall the precipitous decline in science interest on the part of the Vietnam generation.

The late Soviet physicist Artem Alikhanian told this story: During the siege of Leningrad in World War II, he and some colleagues were excused from full time defense work in order to work on the design of a synchrocyclotron - the accelerator which was eventually constructed in Dubna in 1955.

Now a siege is clearly a socio-economic crisis of major proportions and I interpreted Alikhanian's story as evidence that someone in authority assumed they would overcome the crisis and that a high energy accelerator would be important for society in the future. It may be that the Soviet authority was farsighted enough to foresee a utilitarian role for what seemed to the physicists like a purely cultural activity.

Science, the cultural part, has a deep influence on general philosophy - on the way humans think of themselves and their place in the world. The "spaceship earth" concept of a new humility and of even newer environmental concerns could hardly have been invented before Copernicus. And, in spite of discouraging setbacks e.g. Creationism and Laetrile, vast progress has been made in general scientific enlightenment. Keith Thomas,[8] in telling of the repeal of Witchcraft Laws in England in 1736, concludes:

> "The absurdity of witchcraft could henceforth be justified by reference to the achievements of the Royal Society and the new (Newtonian) Philosophy."

and he quotes Richard Bentley:

> "What then has lessen'd in England your stories of sorceries? Not the growing sect of free thinkers but the growth of Philosophy and Medicine. No thanks to Atheists but to ... the Boyles and Newtons."

Science makes its own contribution to general culture along with art, literature, music and the social sciences. In this sense, it creates a society whose well-being and energy sufficiency are worth preserving, to paraphrase R. R. Wilson.*

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* In a Congressional hearing on the Fermilab budget, Wilson was asked if the accelerator would help national defense. His now classic rejoinder was: "No sir, but it will make the nation more worth defending."

That this culture is widely appreciated may be judged from the estimated audience of 8-10 million who tuned in to Carl Sagan's TV series, Cosmos, or the almost equally wide following for Jacob Bronowski's BBC series, the Ascent of Man.[9] There is of course more to the measure of the state of society than the GNP. There is more to the quality of life of the individual than his annual income. Just as it would be inconceivable to have a civilized society without art, without music or without concern for its history and anthropology - so it is not possible to imagine doing without the national and the international scientific heritage.

To bring this rhetoric closer to issues of policy I assert that without the proper recognition of the cultural and aesthetic significance of science, it would become vastly more difficult to engage the scientifically creative individual and hence the probability for technological progress would be seriously diminished. Perhaps the most seminal influence of scientific culture on society is the commitment to a rational view. The time scale is agonizingly long so we proceed to the next effect.

III. Direct Effects

How can the direct application of a successful breakthrough in VBR, and, in particular, in particle physics result in a change in energy availability?

Obviously when one tries to extrapolate frontier research over a "long term" period, one is indulging in grandiose speculation. Responsible colleagues shirk this task almost as a tradition. Ernest Rutherford is reported to have said: "Anyone who expects a source of power from the transformation of these atoms is talking moonshine." This was said five years before the demonstration of fission by Hahn and Strassman. The real danger is that speculation can lose contact with experimental realities and cease to have even the remotest scientific base. Nevertheless it would again deny all of the lessons of history if the leading energy technology of, say, the year 2200 is one of those now considered prime candidates. If we are to be guided by history, we are challenged to propose mechanisms at least as bizarre as many of our current technological miracles would appear to an 18th century savant.

What are the constraints of physics? We do believe in the law of Conservation of Energy. This end-product of a long and evolving concept is rarely counted as a credit to basic research in saving untold millions which might otherwise be spent in the Perpetual Motion Section of DOE's Division of Energy Research! Given that, we can compare the energy yields per gram of some of the standard sources:

Coal or oil burning ~ 5 x 10^4 joules/gm

Deuterium-Tritium Fusion ~ 2 x 10^{11} joules/gm

Total Mass Energy ~ 10^{14} joules/gm

The last line is simply the result of converting all of the rest mass of a gram of matter into energy. There is no unquestioned law of physics which prevents this from someday being used to supply useful energy. In fact, one of the most exciting happenings in particle physics is the search for processes which in principle would make mass energy conversion more thinkable i.e. the search for non-conservation of baryons. But even if baryon conservation were rigorously true, kind nature could provide ways of using almost all of the rest mass.

There is a story to establish the respectability of such far reaching speculation. In 1973 Nobel Laureate T. D. Lee and his Columbia colleague Gian-Carlo Wick[10] pointed out that under unusual conditions of nuclear density and size, a phase change could take place in which the effective rest mass energy of bound nucleons could fall to a small fraction of their normal free value. The result would be the radiation of almost 1000 MeV/nucleon. If this could be organized to happen to all the nucleons in such super dense complex matter, close to 10^{14} joules would be available per gram - and the entire world's annual energy needs in the year 2000 could be met with a few tons of water! Under what conditions can matter be made to behave in a way conducive to this kind of conversion? One very speculative possibility would be in the collision of very massive relativistic nuclei e.g. uranium-uranium collisions. In terms of particle beam intensities, this could yield about 1 gigawatt of electrical power per milliampere of interacting uranium ions.

A central prediction of Grand Unified Theories, in which strong, weak and electromagnetic forces are unified, is the instability of the proton. Not to worry, the lifetime estimates are such that only a few protons out of 10,000 tons of matter would disintegrate per year. The interesting question then is whether one can stimulate the decay by altering the environment. In principle the answer is yes - according to cosmologists who are applying these theories to conditions in the early universe. There is a close analogy to fusion. If the temperature is raised, the barrier to fusion can be overcome and fusion processes can take place. Temperatures were high enough in the very young universe and baryon decay was then the norm. Although present day accelerator collisions simulate conditions within 10^{-13} seconds of the big bang, we have a long way to go before reaching that critical temperature. However there may perhaps be other microscopic environmental changes which will do the job. Unless we learn much more about the constituents of the proton, not much progress can be expected here. This is not to suggest a crash program on quark energy - remember that we are way out on the superextended limb of speculation.

What about matter-antimatter annihilation? This is useful for compact storage of energy and appears in so unwhimsical a publicasion as the Jet Propulsion Laboratory Tech Memorandum 33-7222(1977). The goal was space travel and the subject became respectable enough to have an acronym, M-AM. The trouble is the production and storage of antiprotons. At Fermilab we are designing a source (not for space travel!) which will yield > 1 antiprotons, for each 10^5 incident 100 GeV proton, collected and stored in a magnetic ring. To do anything practical would require intensity improvements over our present capabilities of about a factor of one million, a ways to go.

Let me recite another anecdote concerning the possibilities of direct application of VBR to energy production. The author is Luis Alvarez[11] (1968 Nobel Prize) and the process was the discovery of catalysis of the Hydrogen-Deuterium fusion by muons in 1956. The research was on the properties of exotic particles as observed in a hydrogen bubble chamber. In Alvarez' words:

> "We had a short but exhilarating experience when we thought we had solved all of the fuel problems of mankind for the rest of time. A few hasty calculations indicated that in liquid HD a single negative muon would catalyze enough fusion reactions before it decayed to supply the energy to operate the accelerator to produce more muons, with

> energy left over after making the liquid HD from sea water. While everyone else had been trying to solve this problem by heating hydrogen plasmas to millions of degrees, we had stumbled on the solution (it had been predicted theoretically by F. C. Frank in 1947) involving low temperatures instead."

Of course the calculations were in error and muons would not do - their lifetime is too short. However, if the muon had been stable, or if a stable heavier lepton does exist, this process could work. Catalysis by metastable particles was not on any energy expert's list of long range prospects, nor should it have been.

In a similar vein one of the discoverers of the quark model, George Zweig, has speculated deeply about the usefulness of free quarks, should they exist and be discovered, in the conversion of mass to energy.[12] Quarks have achieved universal acceptance as the constituents of strongly interacting nuclear matter. The fundamental issue is whether they can exist in the free state. One experiment, now repeated several times, provides evidence that free quarks of one third integral charge exist.[13] If this is so, the conservation of electric charge insures that the lowest mass quark is stable.

One way Zweig makes energy is by the same fusion process discovered by Alvarez. The massive quark binds two deuterons via a Bohr orbit that is smaller than ordinary D_2 by the ratio of the quark to electron masses, and the fusion process is greatly enhanced. The quark is then free to do it again. Zweig estimates that one mole of quarks can catalyze ~ 10^{16} Btu/year but this does not include the unknown capital cost of the quarks. Zweig also considers cyclical catalysis in which a sequence of charge changing reactions results in a larger net release of energy. In an appendix to his Science article, Zweig provides elaborate engineering details relevant to concentrating quarks and nuclear reaction management.

S. Glashow (Nobel Laureate 1979) and R. Cahn have their favorite catalyzer - massive stable hadronic particles.[14] These are, in unified models candidates which weigh from 10 to 100,000 times the mass of the proton. It is clear that the field is rich in remote potentialities.

The foregoing examples deal with particle physics and energy. Clearly there are other fields of VBR and other technologies that are of great concern to society. We treat a few of these below. We consider it a success if VBR research has an important effect on a more applied science e.g. nuclear, atomic or solid state physics, chemistry, biology or medicine. It would be a major challenge to economic science to trace these successes until they could be converted to dollars earned.

Magnetic Monopoles[15]

Whereas single electric charges exist, a long standing asymmetry in Maxwell's Equations precludes the existence of single magnetic charges - monopoles. But their existence has been discussed on the basis of symmetry and of Dirac's connection of monopoles and the quantization of Charge. These developments intensified experimental searches. Recent advances in gauge theories (unification theories) have further enhanced interest in the existence of such particles. In 1975, a tentative identification of a cosmic ray event as a monopole generated a rash of speculations on practical applications. In one hard headed industrial research laboratory, seven disclosure (pre-patent) letters were written on the consequences of the existence of monopoles ranging from ship propulsion to energy storage devices. The reason for this exuberance has to do with the curious properties of monopoles which are very strongly coupled to ordinary electric and magnetic fields.

Neutrino Prospecting[16]

High energy neutrinos, a fruitful tool of basic research in weak interactions, are capable of penetrating the earth with a very small probability of making a collision. A stream of 10^6 neutrinos of $\gtrsim$ 100 GeV would, on the average, make ~ 100 collisions on the way from Chicago to Ulan Bator the short way. Several proposals have recently been made to use this tool as a probe of the earth's density and, consequently, a possible tool for locating gas, petroleum or heavy ore deposits. These approaches in general require accelerators which are "next generation."

Having succeeded in embarrassing my colleagues by the foregoing speculations, I now list some recent cases of direct applications of VBR, all of postwar vintage.

Genetic Engineering

A dramatic and very recent example of the applications of VBR to technology comes from molecular biology. The historical origins of molecular biology are much more closely interwoven with applications going back to Pasteur and Tyndall. However, the present situation is adequately described in a recent comment by James Watson:[17]

> "The elucidation of the double-helical structure of DNA in 1953 created no stir outside of the small band of scientists who were active in the field... we could now tackle genetics on the molecular level ... and acquire key insights about gene structure and function. But we did not foresee any immediate practical consequences for the world about us and much less any reason why the man in the street ... should know we exist."

The work of Boyer and Cohen in 1973 changed all this and Nobel Laureate Watson (1962) goes on to say:

> "Although previously there had been numerous speculative scenarios for altering our genetic compositions, not one had a ring of plausibility distinguishable from science fiction. Now molecular genetic research has the power to alter life on a scale never before thought possible."

Note the crucial time interval ~ 30 years from basic research discovery to a mushrooming bioengineering industry.

Applications of the discovery of genetic recombination are headline material - often in the Wall Street Journal. A recent issue of Scientific American[18] is devoted to Industrial Microbiology. In this issue you can learn about applications of industrial microbial genetics to medicine (e.g. immunology and insulin and interferon manufacture) to energy (conversion of biomass to liquid fuel and chemicals), to agriculture (nitrogen fixing), sewage detoxification, production of pharmaceuticals, oil spill control and metallurgy to name a few. A future study I will propose below should be able to assess the dollar volume of business activity generated by this direct application of VBR.

Muon Spin Rotation (μSR) [19]

In 1957, as a result of a theoretical suggestion of T. D. Lee and C. N. Yang, parity violation was discovered in the chain of decays:

$$\pi^+ \to \mu^+ + \nu \text{ and } \mu^+ \to e^+ + \bar{\nu}_e + \nu_\mu$$

This discovery[20] had a tremendous impact upon our understanding of weak interactions and, because it dealt with a deep symmetry, on all of theoretical physics. Lee and Yang won the 1957 Nobel Prize for this work. The proof of parity violation lay in the fact that muons emerged from the accelerator with a high state of spin polarization. In the decay of muons, the spin state could be deduced from the asymmetry of electron emission about the direction of the spin axis. Since a spinning muon responds sensitively to magnetic fields, the original paper pointed out that positive muons, stopping in matter, could act as probes of atomic magnetic fields. In 1980, the Second International Conference on Muon Spin Rotation was held in Vancouver. Applications are to be found in nuclear, atomic and solid state physics as well as in chemistry and biophysics. Muon probes have been used in interaction with nuclear magnetism to study lattice distortions, defects, trace impurities and μ^+ locations and diffusion. Interaction with d- or f-electrons measures internal fields. Temperature effects and trapping at defects are also studied in contact interaction in metals with conduction electrons where the electron spin polarization and local density of states are studied. Muons in type I and II superconductors probe flux-line flow and magnetic field distributions. The muonium atom (μ^+e^-) is formed in semiconductors and insulators for muonium chemistry, reaction rates and isotope effects since the muon behaves like a tagged H-ion. An example of the power of μSR is the recent application to ternary rare-earth rhodium borides in which the relationship between superconductivity and magnetic ordering are studied by this technique. μSR has also served to clarify transitions in spin-glass systems. All in all, these applications are a long way from the particle physics concerns with the properties of pions and muons.

Nuclear Magnetic Resonance (NMR)

My final example is derived from the work of E. M. Purcell, F. Bloch and others[21] and based upon the radio-frequency resonance technique used by I. I. Rabi and his students. These showed that protons in bulk matter, situated in an external magnetic field, will absorb energy from an r.f. oscillator at a precise frequency, given by the magnetic moment and the applied field. The motivation was to measure the magnetic moment of protons and other nuclei. Early applications, largely to other research tasks, were to provide precise measurements of magnetic fields. This process became important in any application where the regulation of magnetic fields was important.

The application of this technique to chemical and biochemical systems is extensive. Spin-spin interactions between nuclei mediated by atomic electrons can be studied and quadrupole moments measured. Relaxation effects have become indispendable in chemical studies of binding. Most recently, NMR Imaging has become important in noninvasive medical diagnosis and biological investigations.[22]

For completeness the well known and eminently relevant comments of H.B.G. Casimir[23] must be included in this compendium. Casimir, with experience in academic and industrial research wrote:

> "I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon.
>
> "Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in and had not contributed to wave mechanics or the theory of electrons in solids. It so happened that inventors of transistors were versed in and contributed to the quantum theory of solids.
>
> "One might ask whether basic circuits in computers might have been found by people who wanted to build computers. As it happens, they were discovered in the thirties by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics.
>
> "One might ask whether there would be nuclear power because people wanted new power sources or whether the urge to have new power would have led to the discovery of the nucleus. Perhaps--only it didn't happen that way, and there were the Curies and Rutherford and Fermi and a few others.

> "One might ask whether an electronic industry could exist without the previous discovery of electrons by people like Thomson and H. A. Lorentz. Again, it didn't happen that way.
>
> "One might ask even whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.
>
> "Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz who emphasized the beauty of physics and who based his work on the theoretical considerations of Maxwell. I think there is hardly any example of twentieth century innovation which is not indebted in this way to basic scientific thought."

In summary, given a respectful interval, 30 years or so stands out, major advances in VBR from about 1600 to about 1940 have had a powerful impact upon technology, science and the general welfare. There have been critics who say this historical guide is irrelevant because VBR since the 1940's has grown too abstract and remote from human experience.[24] We have indulged in some blatant speculation to indicate that the historical guide could be valid. We have surely left out many examples from fields about which I am ignorant.

Progressively, human beings have accommodated to drastic changes in their environment like being surrounded by metals, by electromagnetic vibrations full of information, by supersonic travel and, vicariously, the environment of near earth space. There does not seem to be any very convincing argument that historical guidance will cease to be valid in the last half of the 20th century. The rate of discovery leading to direct application continues to be large enough to encourage continued investment.

IV. Indirect Effects ("Spin-off")

A. Introduction

VBR involves experimental research at the frontier. Traditionally experimentation requires the invention of novel instruments and techniques which are later found to have applications in industry, creating goods and services which add to the GNP and to other research areas, which in turn may have direct or indirect effects on technology.

That this is a two way street, that instruments often come to basic research from technology or invention and contribute crucially, is not very relevant to this paper. We mainly want to make several points here:

(1) The technology spun off from VBR pays back to the U.S. treasury, at the least, a substantial fraction of the cost of the basic research. This pay back is in the form of taxes collected on the new business generated. There is additionally a pay back in the new products themselves which may contribute to health care, to the good life, the general well being and security of the public. Only part of this is quantifiable. The accelerator that destroys a tumor generates profits for the manufacturers, for the doctor and

than the laboratories of high energy and nuclear physics but which were generated by the company's interaction with CERN engineers and physicists. From the conclusion of the CERN study:

> "Since its creation in 1952 and to the end of 1973, CERN received 3,500 MSF (about $1.9B at today's rate of exchange) from its Member Countries. Out of this 877 MSF were spent by CERN in those European firms which are considered in this study. These expenditures created an estimated total utility of 4,860 MSF which will be accumulated by the end of 1978."

The author then cautions against the quantitative gain these figures imply but affirms that it is safe to assume that the balance is indeed positive. Other systematic studies from somewhat more specialized points of view have been carried out by economists, for example Edwin Mansfield and his collaborators, Richard Nelson, Carl Kaysen, E. Denison and Z. Griliche.[26] A center for such analyses is the Science Policy Research Unit of the University of Sussex.[27] The general conclusions support the economic value of basic research although these analyses are too complex to paraphrase here and in general do not clearly distinguish between VBR and general R&D. While awaiting a definitive future study, we are left with anecdotes. Some of the anecdotal illustrations listed below are solid, some are promises. Here again I am appealing to fields with which I am familiar. Crucial spin-offs must also come from table-top atomic physics research as well as from Big Science.

B. Particle Accelerators [28]

The invention of particle accelerators was motivated by the desire to bombard nuclei with accelerated projectiles in order to extend the experiments of Rutherford, Chadwick, Joliot and others - who made use of natural radioactive nuclei as sources of projectiles. Cockcroft in England succeeded with an electrostatic accelerator and immediately applied this to the nuclear disintegrations of Lithium. E. O. Lawrence's cyclotron in 1932, ushered in the modern period with acceleration to 1 million electron volts. Fermilab houses an accelerator which, in 1976 achieved the world's record of 500 billion electron volts. But in the interim, there are well over 1000 particle accelerators in the U.S. devoted to a wide variety of socially and economically productive activities - activities which preserve and enhance the quality of life of our citizens.

1. Accelerators were used extensively to provide the data which made the design of nuclear fission reactors possible. Similarly the data was provided to form the basis of nuclear fusion devices which are now under intensive study and prototyping. In a less direct vein, radiographic electron linacs are routinely used to inspect the thick steel vessels and pipes used in building nuclear reactors.

2. Cyclotrons produce a large fraction of the radioactive isotopes used in medical research, diagnosis and treatment, e.g. radio iodine for goiters. Radioisotopes now contribute several hundreds of millions of dollars a year in sales. They are used in various industries e.g. monitoring and control of thin films.

3. Electron Accelerators are used in industry for non-destructive testing, as thickness gauges and inspection devices and for sterilization. In the last application, electron beams have been used to disinfect sewage so that it can be used as fertilizer.

4. Particle accelerators. About 1000 medical accelerators are used in hospitals in the United States for treatment of cancer. About 350,000 patients per year are treated in these hospitals with megavoltage radiation. The charges for this irradiation, exclusive of physicians fees and hospitalization, total about $1 B annually. The annual sales of medical accelerators and associated equipment in the U.S. approach $100 M. The development of medical accelerators has been an important factor in the continual improvement in cure rates for cancer. These electron linear accelerators produce penetrating x-ray and electron beams. Clinical research is proceeding on the potential of particle beams produced by other accelerator types; i.e., neutron, protons, pions and heavy ions.

5. Heavy Ion Fusion. One approach to the fusion energy problem with impressive adherents is HIF. Intense accelerated beams of heavy ions are used to compress and ignite small pellets containing thermonuclear fuel. Currently envisioned accelerator drivers fall into two categories - either induction linacs or systems of RF linacs and storage rings with induction linac modules in the final beam lines. One talks about ion beams of mass $\gtrsim$ 200, accelerated to $\sim$ 10 GeV with ion currents of $\sim$ 10 kA. The concept is firmly based upon a technology resulting from the past 30 years of development of basic research accelerators for high energy and nuclear physics.

6. Intense Pulsed Ion Beams[29] Out of the pulsed power technology of relativistic electron beams have sprung a few very successful techniques for producing terawatt (10^{12}W) beams of light ions. The motivation is application to fusion programs, offering alternatives to Tokamak and laser-driven inertial confinement devices. In addition to applications to fusion this spin-off from electron accelerators may be applied to laser excitation for communications, photochemical processes, and the development of intense neutron sources.

7. Ion Implantation Accelerators The production of integrated circuits - one of the most explosive of new technologies - now makes use of ion implanting accelerators. These ion implanters employ accelerator technology throughout e.g. ion source, accelerating column, beam transport magnets, vacuum and control systems. They are used by the semiconductor industry in ever increasing numbers (1000 are now in use at a cost of $300M) and produce about $8B annually in products which in turn make other products like computers and microprocessors. In Europe the corresponding economic impact is $1.2B and is $4.4B in Japan. Implanting is also becoming important in producing alloys with a greatly reduced requirement of the rare metals in the mix. This is an ideal example of designing around the increasing shortage of chromium, vanadium, etc.

8. Oil Well Logging Accelerators are used in oil and gas well surveys - they are actually lowered into wells, and their particles probe surrounding material to give accurate chemical analyses of what is there. Industry estimates the cost of nuclear logging equipment at ~ $900M per year.

9. Synchrotron Radiation[30] Electron accelerators are source of synchrotron radiation - a vital tool for research in biology, solid state physics, chemistry and in industrial processes. Synchrotron radiation SR, is the electromagnetic radiation generated by charged particles being deflected in magnetic fields. It plays a major role in the design and operation of circular electron accelerators. Theoretical work on SR goes back to earliest times and has been treated by such luminaries as Pomeranchuk and Schwinger. Design of postwar electron machines had to cope with the significant energy loss and backgrounds to experiments represented by synchrotron radiation. By mid 1960's research making use of the radiation began to be parasitic on the high energy physics uses of accelerators at Frascati, NBS, Tokyo and Hamburg. Today some 25 experimental stations in the U.S. serve over 400 users in rings, some dedicated solely to the use of synchrotron radiation, providing five orders of magnitude more intensity in the vacuum UV and X-ray region than conventional sources such as x-ray tubes. World wide over thirty machines (eleven wholly dedicated) provide some source of SR. The use of multi-GeV electron

storage rings has greatly extended the capabilities by providing a stable, very wide spectral range, natural collimation, high polarization, pulse time structure and small source size.

SR attracts a very broad interdisciplinary set of customers: surface physics, catalytic chemistry, protein crystallography, amorphous materials science, trace element analyses, many areas of biochemistry, microscopy, lithography and tomography. Some indications of the directions of this work:

i Replication of microstructures by soft x-ray lithography. The possibility exists for example, for integrated circuits to be produced with 100 to 1000 times higher density of elements than is now possible.

ii Time-resolved spectroscopy. Conformal changes in biological materials can be studied on a subnanosecond time scale.

iii Soft x-ray microscopy. Life specimens may be studied in atmospheric environment with chemical element discrimination at high resolution.

iv Trace element analyses by x-ray fluorescence at order of magnitude greater sensitivity.

v Tuneable UV is used to vary the escape depth of photoelectrons emitted from a solid surface. Applied to study of chemical bonding and electronic structure at semiconductor - metal interfaces for device applications.

vi Soft x-ray absorption spectroscopy has been applied to the determination of the structure of catalysts. Applications are to accurate models of structure and surface processes.

10. Radiation Processing - under particle bombardment, materials change properties and this has given rise to a variety of new and improved products: shrinkable plastics, insulation improvement in electrical wiring, plastic baby bottles that can be boiled. The value of such products in 1981 is about $1.4B.

All of this activity, generating goods and services that must come to many billions of dollars annually, was spun-off from the inventors curious about the nature of nuclear forces and determined to devise powerful instruments of attack. To do full justice, we must also cite the spin-offs from the spin-offs. The technology of accelerators covers a wide spectrum of disciplines: ultra high vacuum techniques, high power radiofrequency, precision beam optics, properties of materials under very energetic bombardments, electronic controls, etc. For example, the Klystron was invented by the Varian brothers at Stanford, stimulated by the desire to improve on the facilities for x-ray and nuclear studies. This device became the generator of high power radiofrequency for radar. Another example: the accelerator structure invented for the "meson factory" accelerator at Los Alamos is now used in most of the x-ray radiation therapy machines in this country. Accelerator radio frequency techniques applied by people skilled in their use have led to the cure of "cancer eye" a pernicious cattle disease. As we will note below, superconductivity and cryogenics are some of the newer technologies being applied to accelerators and, in turn, being influenced by the accelerator community.

C. Detection Instruments and Techniques

The accelerators in high energy and nuclear laboratories provide bombarding particles. The experimenters bring detection instruments which must be continually improved in order to make the increasingly sharper measurements of subnuclear processes. Again we have a glorious history - and I enumerate an incomplete list. It is indicative of the field that periodic nuclear instrumentation conferences are co-sponsored by the Institute of Electrical and Electronic Engineering.

1. Particle counters e.g. Geiger counters, ion chambers in olden times, scintillation counters coupled to sensitive photomultipliers today etc. were invented to register radiation for studies of nuclear phenomena. These are essential ingredients in many of the applications of particle accelerators listed above.

2. In order to determine trajectories, particles must be registered at several places along their path (without disturbing the trajectory, of course). This generated the invention of digital circuitry, for counting, for coincidence registering, for measuring time intervals etc. These circuits became the prototypes that sparked the development of the high speed digital computer. The basic research laboratories were forced to push on the speed and sophistication of digital electronics and they deserve a large share of the credit for the spectacular developments in high speed computers.

3. Research laboratories provided the earliest stimulant to small, innovative computer companies to develop small computers for immediate application to data processing and registration. These small companies (DEC, SDS,...) evolved to create a new situation in the U.S.: computer industry competition. A major source of sales for DEC's PDP1 was the high energy and nuclear labs. A former Vice President for Research of IBM, Emmanual

Piore, has stated that the high energy physicists were an important source of pressure towards higher speed and more powerful central computers.

4. Sodium iodide with thallium activation was developed by Hofstader at Princeton as a tool in carrying out fundamental studies of γ-nuclear interactions. He stimulated a chemical company to grow larger crystals and ultimately sparked a $50M/year business in medical diagnostics and oil well logging.

5. Pattern Recognition: Visual detectors e.g. the bubble chamber, take several millions of photographs of nuclear happenings per year. Rapid systems for automatic scanning of complex arrays of tracks have been devised - signals are fed to a computer which processes the information, recognizes track patterns, records precise coordinate information. These techniques of pattern recognition and signal processing have been copied by other research disciplines, by astronomers and biologists. Whether or not they are used in satellite surveillance or in interpretation of landsat photos I do not know. Allan Cormack, a high energy physicist at Tufts won the Nobel Prize for his contributions to computer-aided tomography, a related technique.

6. Cerenkov counters and Stationary Solar Energy Concentrator: In high energy physics the radiation emitted by particles passing through a medium is a valuable measure of the particle's velocity. Since the light is very weak, various light collection techniques have been invented. One of these, by R. Winston of University of Chicago, was applied in 1973 to large scale solar energy collectors and had the great virtue of not requiring tracking of the sun. As a result, stationary solar concentrators are being manufactured today by at least six companies and deployed on a substantial scale. To date it is estimated that the sales are about $40 million.

7. Data Processing Techniques and New Computer Architecture As early as 1960, high energy and nuclear experiments were involved with the necessity of handling huge flows of data in real time so as not to saturate the data storage capacity. The need to organize the data, construct filters, classify data significance, do monitoring of data quality and

detector performance and make decisions - all in real time intervals, has been decreasing steadily, from milliseconds to tenths of microseconds. The most recent work is based on hardware processors.

As the complexity of hardware processing tasks have increased, the resulting arrays can be recognized as evolving into new forms of computer architecture. A recent Fermilab proposal[31] contains this description:

> "We will design a number of simple hardware modules with which one could construct the solution to any specific problem with the full generality of a standard Von Neumann machine. We have accomplished this with a few modules sharing among themselves considerable common structure. ... a typical problem will have a hardware solution consisting primarily of modules chosen from a finite set ... Such a computer architecture may eventually be fully programmable for general purpose central computation... "

The point here is that we believe the central computers of the next generation will lean heavily on the developments taking place today in our experiments where, for specific problems now, four orders of magnitude more speed (or accuracy) are available than from the multimillion dollar central computer.

These techniques are widely applied in other scientific disciplines (e.g. satellite experiments, radio and optical astronomy, electron microscopy scans of biological structure) and most recently in the expanding information processing industry. It is for this reason that Bell Laboratory employment advertising in the Chicago area has specified High Energy Physics experience as being particularly valuable.

8. Fast Electronics and Data Busing We have already noted the basic innovations in circuitry made by physicists in research involving nuclear counting. Many of the physicists and engineers so involved have gone off to form companies which would supply

research customers. Some of these are LeCroy Research Systems, Chronetics, Ortec, EG&G. LeCroy, a physicist out of the High Energy group at Columbia University, does about $20 million annual business, 40% of which is outside of high energy physics. Many of his products, specified by high energy physics requirements, have been applied to fiber optics work, transient recording, fusion research, radar ranging and Controls.

The High Energy Physics community has done much in standardization and, chronologically, we have had NIM, CAMAC and, most recently FASTBUS standards. NIM (nuclear instrumentation module) was designed in the high energy and nuclear VBR labs and introduced in 1964. The total investment in NIM electronics is over one billion dollars with a continuing world market of $50M per year. About 20 U.S. companies (and 50 foreign vendors) supply NIM devices to nuclear and industrial laboratories. CAMAC was developed by the European high energy community in 1969 and modified by the U.S. labs in 1972 to become a worldwide standard, utilizing TTL electronics. In the U.S. one company[32] alone (started by a former Fermilab employee) provides commercial products to the automotive, chemical, power, glass, petroleum, steel, aluminum and defense industries. Again this is a $50M per year activity. We are now seeing software spinoffs associated with computer interfaced CAMAC modules. More recently the needs of the high energy laboratories have surpassed CAMAC capabilities and, together with CERN and other European labs, they are developing a much more powerful standard, FASTBUS, based upon ECL circuitry.

D. Superconductivity and Cryogenics

The intimate coupling of basic research in several fields and technology is well illustrated by the story of superconductivity. The discovery of superconductivity by Kamerlingh Onnes took place in 1911. Onnes observed that a thread of mercury, frozen by liquid helium, offered no resistence to the conduction of electricity. The next most significant development perhaps, was the quantum mechanical theory of the condensation of conduction electrons by Bardeen, Cooper and Schrieffer in 1957. About this time Abrikosov organized the theory to include the subject of alloys by distinguishing Type I and Type II superconductors. In this very incomplete history we are still in the VBR phase. Applications seemed improbable because the possibilities of interesting critical fields were remote and the question of current density was not considered at all. Enter, in 1961, the intuitive inventor Bernd Matthias and the discovery of Nb_3Sn which became superconducting at the elevated temperature of 18^oK, with a critical field in excess of 20 tesla.

Many technical problems had to be solved before one could apply this principle, for example, in the construction of a superconducting (SC) magnet.[33] Such a magnet must be able to enter the normal state safely. There are problems of premature quenching at currents well below the critical current (training). Stability against unstable induced currents due to changing fields influenced the design of the wire. There were problems of ductility of the alloy. Many of these problems were solved in the accelerator physics laboratories because of the benefits of superconducting magnets for particle physics research. Large constant field magnets were built in the 60's at Brookhaven, Argonne and CERN. Vigorous development went on at Brookhaven, Rutherford Lab (U.K.) and, in the 70's, at Fermilab on developing pulsed magnets which would not be quenched by the rapidly varying fields needed for accelerators.

The interaction of the Laboratory scientists with the industry in the manufacture of alloy, wire and cable greatly advanced the industrial capability to produce superconducting cable. In parallel with superconducting magnets, the associated cryogenics - liquid helium refrigerators of very large capacity, efficient transfer lines, cryogenic vacuum vessels and electronic controls to monitor these large systems had to be developed. At the present time by far the most massive application of superconductivity is the construction of the Fermilab Energy Saver where 1000 superconducting magnets, each 7m long, with peak magnetic fields of 4.2 tesla and storing 1/2 Megajoule of magnetic energy are being assembled. The associated cryogenic system consists of 24 large 900 W refrigerators backed up by a Central Helium Liquefier capable of producing 5000 liters of liquid helium per hour.

We have, in this story, basic research in the property of metals at low temperature leading to a discovery which has developed into a technology, largely (not exclusively) by the requirements of basic research in particle physics. There is now looming a set of promises for practical applications that will, if only partially realized, have profound implications in energy production, transmission, transportation, electrical power generation, fusion power, mining, water purification and whatever else ails vou or so it seems:

1. In the electric-power industry large SC magnets are proposed for application of the magnetohydrodynamic technique (MHD) of power generation. A high temperature (coal or oil fired) plasma is forced through the strong magnetic field at high velocity and resultant ion separation generates an electric field. A 20 megajoule SC magnet was constructed at Argonne for this application.
2. In fusion research, the promising Tokamak confining field configuration has lead to a development project in which six large and very high field (8 tesla) magnets are to be evaluated at Oak Ridge.
3. The Livermore mirror-fusion test facility is constructing a pair of SC coils with 7.7 tesla and a stored energy of 400 joules.
4. Both Westinghouse and General Electric are building compact SC alternators for aircraft service. Westinghouse is also constructing a 300 megawatt rotor for electric power generation. SC alternators have large efficiency advantages over conventional electric generators. For a planned 1200 MVA SC generator, there are substantial cost benefits from the savings of 420 billion BTU due to efficiency. Lower construction costs add to the savings. Additional benefits follow from the smaller size, weight, transport costs and plant building costs.
5. GE and the Garrett Corporation are developing 3000 horsepower dc superconducting motors and a 3000 horsepower generator for electric propulsion of ships.
6. Large SC magnets have been proposed as load smoothing power reservoirs for electric-power systems.
7. Superconducting transmission lines are being studied as an efficient means of transporting electrical power from source to customer. This R&D is a direct spin-off of the Brookhaven high energy

SC work, where a prototype of 10^9 volt-ampere capacity is under construction. These lines should permit more convenient siting of nuclear or conventional power plants away from urban centers.

8. The Brookhaven group also instigated investigation of a new form of transportation: magnetically levitated trains. These are to run at high speed (~ 300 mph), suspended by SC magnets, off of a rail which is part of the propulsion system. A test train in Japan operated over a 7 KM track at a speed of 330 mph. An imaginative extension of this potential application is the Rand Corporation "tubecraft." A system is proposed of connecting major cities by an evacuated tunnel in which a magnetically suspended car can travel at 1400 mph. The authors estimate that the $80B cost would have a 30 year payback time.

9. High Gradient Magnetic Separation (HGMS) is another field rich in promise for industrial application. Conventional water-cooled magnets are being used to magnetize filaments of ferromagnetic material. The very large magnetic gradients can trap and remove weakly paramagnetic particles with diameters as small as a few microns. These separators are used now in three commercial applications:

   a) Kaolin clay purification for paper and ceramics industry
   b) Industrial waste water treatment
   c) Coal desulphurisation

   The replacement of conventional magnets with SC magnets in these applications will yield higher process rates at lower costs.

In summary there is a potential for many tens of billions of dollars of industrial applications which may result from the superconductivity story. Some fraction of these potential credits must go to VBR. Vigorous research continues in the particle physics labs in anticipation of even higher useful fields i.e. in excess of 10 tesla. These may use new materials, lower temperatures or both.

Type II materials are known that retain superconductivity up to 50 tesla. At these extensions of fundamental properties new science may be reached.

E. Theoretical Physics Applications 34

Modern particle theory rests on Relativity, the Quantum Theory and the dramatic evolution of Quantum Electrodynamics (QED) in the 1940's which was sparked by the work of Tomonoga, Schwinger, Feynman and others. Progress in weak interactions and in the subsequent synthesis which is called Electroweak Theory was developed by Gell-Mann, Lee, Yang, Weinberg, Glashow among others. Strong interaction physics developed a quantitative, field theoretic stance (QCD) with Gell-Mann, Bjorken, Glashow and many others. All of these developments were made possible by data which poured out of the VBR laboratories, ranging from the Lamb shift and other precision atomic physics research, the cosmic rays, nuclear research and the high energy physics accelerator laboratories. Theoretical physics has debts to mathematics, condensed matter theory and other disciplines but here we address only the one direction - from VBR theory to other fields, some scientific, some technological.

1. Condensed Matter Physics. The language of quantum field theory and Feynman graph techniques are used as a unifying framework for solid state analysis.[a] Particle theorists are trying to understand phase transitions in various media. In fact, a journal

devoted to this interface has been establishshed[b,c].

2. Ideas generated in the Electroweak theory on the solution of nonlinear equations (solitons) are applied to polymer physics and chemistry,[d] in particular the polyacetylene problem.

3. The Feynman path integral methods have been applied to describe propagation of ocean density waves and employed in percolation methods important in oil exploration.[e]

4. Theory does reflect back on mathematics by supplying problems but also, for example, in the contribution of quantum field theory to Functional analysis.[f] Supersymmetry theories of grand unification have made contributions to the theory of Lie algebras.[f]

5. Evaluation of complex Feynman graphs for QCD and QED have given rise to contributions to symbolic manipulation technology.[g] At present, there is much activity in the development of large-scale parallel-processing technology for lattice gauge theory calculation.[h]

6. A large number of more detailed spin-offs can be found, e.g. applications of dual model techniques to design of transmission lines.[k]

7. We have already alluded to the impact on astrophysics - e.g. neutrinos in supernova dynamics, stellar collapse and the closed universe. Black holes, neutron stars and General Relativity closely interrelate with particle theory.

8. Strong coupling (QCD) lattice field theory has been used to solve boundary layer problems crucial in the theory of fluids.[l] Along these lines particle theory techniques associated with the renormalization group have lead to a breakthrough in the theory of turbulence.[m]

F. Production of Trained Scientists

This is a subject that deserves a much more detailed study than will be presented here. Again I have data only for high energy physics. The population of high energy physicists included in the annual DOE census has been increasing, since 1974, at about 50/year. Ph.D. production is about 130/year. About half of this production remains in the field initially but defections take place continuously to set the equilibrium of a net outflow of about 80 Ph.D.'s per year. My experience with graduates of the HEP laboratory at Columbia University (based upon ~ 130 Ph.D.'s since 1951) indicates that the recipient fields vary very widely and include industrial research, college teaching, government research labs (not HEP), biophysics, computer sciences, administration, finance and industry ownership and management. To the above total one should add engineers, technicians and computer programmers who are trained in VBR techniques and are "hired away." The quality of training in high energy physics is a hotly debated subject. This is "big science" and young investigators work in groups that vary from five to fifty. Opportunities for training are superb. Under sensitive guidance a student will have exposure of varying intensity to software, fast logic circuitry, mechanical design and systems engineering. He will have contact with experts who can teach him or, do his work for him - hence the controversy. The good student under the good professor will never lose track of the overall objectives of the research but he will often be part of a large team and must learn how to adapt to and make best use of his teammates. Very often the team is an assembly of fellow students and young postdocs from institutions around the country and from abroad. The association of students with diverse backgrounds is in itself a unique pedagogic experience.

Living in a national laboratory center, he will meet, in conditions of intense involvement, those who will be his professional colleagues. He will be rubbing up against the advanced accelerator technology, he will use the world's most advanced computers and listen to seminars by a continual flux of distinguished physicists. The good student then has an enormous set of opportunities for learning. It is small wonder that he is appreciated by industry and government. It is well known that during WW II, the leaders in the development and engineering of the atomic bomb, radar, the proximity fuse, etc. were academic scientists trained and dedicated to pure research. The trend of a flow of talent from VBR to large technological projects continues to be an important ingredient in science manpower allocations.

V. International Aspects

Typical of the continuous and circuitous nature of the influence of VBR on the socio-politico-economic condition of the nation is the international nature of the enterprise. This aspect contributes in all three time frames: cultural, direct and indirect. That science is fundamentally an international activity needs no long arguments. That scientists form international communities that lead to mutual respect, appreciation, understanding and bridging of vast cultural differences should be generally accepted. That international cooperation in science is a role model and pilot for deeper and more general cooperative activities is more subtle and requires deeper study e.g. how much of the CERN experience was important in the establishment of the common market and other pan-European activities?

The interdependency of advances in VBR stems from a simple and important fact: the number of humans with great creative abilities in science is very small and must be drawn from a population fertile to the creative seed.[35]

The postwar dominance of U.S. science has clearly resulted in a vast influence of the U.S. in world science. It is very likely the U.S. influence that has established English as the defacto language of science. When a Japanese physicist meets an Armenian or a Brazilian at a conference, they will almost surely converse in English. The pre-war European refugees and the postwar "brain drain" were important ingredients in U.S. scientific strength. VBR has the virture that collaboration has, until very recently, been resistant to international tensions, cold war, etc. The Pugwash meetings, sparked largely by scientists, has been an important factor in subsequent negotiations on arms control. Clearly there is much more that can be added here.

VI. Conclusions

Basic research, defined in a rather loose way, is supported at a level of $6B (1983) i.e. slightly less than 1% of the national budget. Of this amount I estimate that only $1-2B is really pure research, i.e. VBR. The rest is basic research which has some association with mission oriented science. The total R&D effort in the U.S. is about $80B roughly half supplied by government. Alvin Weinberg[36] and others have suggested that whereas not-so-basic research and development must be paid for by the direct beneficiaries, basic research should be supported as an overhead on the total R&D effort.

We have indicated that there is an excellent possibility that the costs of very basic research are paid by the short term spinoffs. We have stressed the most recent developments. Even here, direct applications of basic research continue to find applications giving rise to the idea that VBR is an intimate blend of the profound and the practical and that there is no way to erect barriers between knowledge and use. The important cultural influences of science continue to arrive and to impact on philosophy, on modes of human thought and behavior. And all of this is essentially cost free. The implications for policy are quite clear. If my numbers are indicative of what is happening, it becomes crucial for policy makers to critically examine the health of VBR and err on the side of caution so as not to endanger so great a societal bargain. Indicators that all is not well in basic research may be gleaned from the fact that, for example, accelerators representing capital investment of over one billion dollars are utilized only 20-30% of the time. More detailed problems may be gleaned from testimony before Congressional committees. These will not be reviewed here.[37] The substantive conclusions of this paper are the following:

> In order to define a crisp science policy issue it makes sense to separate pure research as defined above, out of the rest of science research since it has recognizably distinguishable characteristics and almost by definition no external constituency.
>
> Pure research, VBR, is a crucial ingredient in the cultural evolution of society. This is a dynamic process and the influence of scientific progress continues to percolate slowly but inexorably into the mainstream of human thought.
>
> Direct applications of basic research have a powerful historical imperative. Some fields, like high energy physics, seem remote from technology but others are not. The very scale of phenomena suggest that if applications are found, they will be momentous.
>
> Spinoffs from this activity have a continuing record of adding high technology products to commerce which may even make support of VBR economically

profitable. VBR is very likely a producer of scientific manpower available for the rest of the R&D activity including energy science and development.

If these observations are correct, then VBR should be supported at whatever level it takes to make the field healthy. Whereas the (very fruitful) exponential growth of the 1950's and 60's may not be a realistic permanent goal, the compression of the past decade is a tragic mistake. Criteria for a healthy level can be defined. A solid indicator is the rate at which creative young investigators come to the fore. Constraints on the availability of people and the innate conservatism of government will serve to keep any resultant growth fairly modest. It remains for someone to substantiate the points made above. In particular the NSF, for example, should undertake a study, utilizing a team of professional economists, industrial engineers and scientists to:

1. Identify the fields of basic research which are remote from application. Clearly there will be grey areas.
2. Carry out a study of the impact of past and ongoing research, field by field. This will involve tracking down laboratory-industry connections and an in-depth followup on the industry performance in exploiting the utility potential generated by the connection.
3. Carry out a manpower study to see if the net output is as indicated. Quality enters here in subtle ways - VBR may indeed retain the best scientists. However, if VBR were to contract seriously, would these stay in any science?

4. Determine a sensible time interval so that VBR is continually monitored and does not coast on long faded glories.

My intention in this paper was to provide a rough guide to a definitive study of the economic and cultural impact of basic, remote, abstract scientific research on the "broader national (and international) interests." The presupposed conclusion of such a study is that the idea of basic science as a national trust is sound and also profitable. I assume this is so persuasive that funding for VBR will soon rise to the level required to restore this subject to better health. There does remain the grave concern, buried in my third footnote, that the risks concomitant with the resulting technology will in fact not be managed successfully, but if we fail here, energy sufficiency will no longer be of concern to society.

Finally, I adjoin a separate addendum which contains a tentative suggestion, not very well thought out, for a mechanism that would carry the conclusions of this paper into science policy.

Addendum

A TENTATIVE POLICY PROPOSAL

Let us assume that the following premises are accepted:

(1) That VBR is an approximately definable activity, easily identified in some cases, in others, embedded in a larger domain now also called basic research.

(2) That this activity is "free" in the sense that there are short term (say less than five years) pay backs so that for example, in FY '83 we can identify a return to the treasury of at least the amount expended annually over the previous several years - this return identified by a close casual relationship to the VBR activity. We note that this is an extreme underestimate of the return to the public.

(3) That VBR also exports highly trained and talented scientists to other fields of research and administration.

Under these assumptions I would tentatively suggest that a new strategy is called for in science funding policy. This would involve creating a separate funding desk, perhaps in the Office of Science and Technology Policy, charged with identifying VBR activities and insuring that these go forward in a healthy manner totally independent of programmatic requirements or of competition with other research activities which have their traditional constituency. This need not require traumatic changes in present administrative structures or even in schisms between, say, VBR biologist and not-so-BR biologists. Guidance from OSTP via the traditional routes with OMB directives and good liaison with Congress could accomplish these ends. The relevant OSTP panel must work to define the key word "healthy" but in general terms the aim would be to find support for any scientific idea that survives stringent peer review. We want to reproduce some fraction of the opportunities that young investigators had in that terribly fruitful scientific period of 1950-1965. This is a goal in which the U.S. public and the policy makers who serve it cannot lose.

Acknowledgements

I would like to thank my colleagues at Fermilab for their criticism and assistance: J. D. Bjorken, A. Tollestrup, A. Brenner, F. Cole, T. Nash, R. Schwitters, J. Schonfeld and J. Appel. Professor I. Halpern of University of Washington provided many critical insights. Lon Morgan of Scientific Measurements Systems provided data on accelerator spin-offs, as did Craig Nunan of Varian Associates. Many others, including the participants in the Workshop, offered constructive suggestions.

Notes and References

1. Curiosity about the natural world and ego are necessary ingredients to the scientific enterprise but they are hardly unique to scientists. The obsession with nature goes back to earliest records; essentially all the societies known to anthropology have embedded concerns with the cultural aspects of the natural world ... about which "it is good to think" (Levi-Strauss). See also Rena Lederman, "Science and the Savage Mind," Princeton Seminar, 1982.

2. Some other disciplines in this remote corner are astrophysics, parts of atomic physics (e.g. parity violation in atoms) parts of nuclear physics, condensed matter physics, mathematics and probably some of molecular biology.

3. It is easy to make a long list: threat of nuclear war, ecological disasters e.g. ozone layer changes, greenhouse effect, acid rain, global oil spills, reactor accidents, shortages of minerals, global climatic changes, increasing vulnerability to terrorism, food shortages, explosive costs of health care. We recognize that all of these are generated by existing technology. The virtues of VBR are increasingly suspect in view of these possible calamities. However, the debate is sophistry. It is too late. Science has delivered an enormous amount on its promise of the good life but both in distribution and in ever increasing possibilities for fulfillment, there is much to do, including the thwarting of potential and real disasters listed above. That these can be managed is the hope engendered by the rational view which must, in this context, be shared by all of society. If we fail, the survivors, if any, may well envy the life of the 15th century peasant.

4. J. J. Salomon, in Science and Society, MIT Press, Cambridge, quotes Renan in L'Avenir de la Science to the effect that "intellectual good" whose value has no fair price, will always remain inherent in the scientific approach. A society is therefore conceivable which would be satisfied with its

accumulation of material goods and which would devote a growing part of its wealth to the enlargement of knowledge solely because it is a good in itself. The aims of the state should be the aims of science since its goals should be well-being and betterment of the body social as a whole and here the increase in knowledge is a decisive factor.

5. Richard Feynman defends science as an aesthetic activity: "Poets say science takes away from the beauty of the stars - mere globs of gas atoms.... I too can see the stars on a desert night, and feel them. But do I see less or more?" - Feynman' Lectures on Physics, Addison-Wesley, Reading, Mass., 1963. The point he and many others make is that rational thinking, by recognizing causes, relationships and mechanisms, adds to the perception of beauty and richness of natural phenomena. "It enhances and humanizes our appreciation of nature."

   Poincaré says it differently: "The Scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it; and he takes pleasure in it because it is beautiful. If nature were not beautiful, it would not be worth knowing and life would not be worth living." Quoted by S. Chandrasekhan in: Beauty and the Quest for Beauty in Science, in Aesthetics and Science, Fermilab, Batavia, Illinois 1979. A very relevant recent text is D. Hofstader's Godel, Escher, Bach New York, Basic Books, 1979.

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9. I could add to these the popular fascination with NASA escapades and the proliferation of science magazines - because they sell! The Book-of-the-Month Club started a science club last year. Bantam Books introduced New Age Imprint - more science books. Harper & Row is producing at least 15 books by distinguished scientists in 1981-2 to explain the scientific process. Richard

Snyder, chairman of Simon & Schuster: "Publishing is the mirror image of society and somewhat presages it. The existence of so many books by scientists means this country is going to enjoy a technological edge in a few years." Communicators of science are proliferating and include Sagan, Jastrow, Bernstein, Dubos, Crick, Watson, Capra, Gould, Leakey, O'Neill, Dyson, the Ehrlichs, D. Hofstader, Attenborough, Zukaw, Lewis Thomas, N. Calder to name a few. Policy makers take note! My appearance and discussion of particles on the Phil Donahue TV show brought over 1000 letters, most of them enthusiastic about the subject. Do we set professionals to study this issue?

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22. G. L. Brownell et al. Positron Tomography and NMR Imaging, Science 215, 619 (1982). Note also in this article the reliance of PET on nuclear counting techniques.

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24. The argument applied to particle physics says that we are dealing with energy transformations that are so high that there is no conceivable macroscopic environment that we can organize to use short of recreating the big bang. Further, say the skeptics, we are now in possession of a reliable theory which allows us to understand this scale. This is a plausible but hardly rigorous argument. As for astronomy, my latest sci fi magazine has us mining mini-black holes for energy. But see also New Scientist 93 75 (1982).

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35. Seminal creators like Newton, Descartes, Einstein, Landau, Yukawa, Fermi and Gell-Mann span a wealth of nations and were each responsible for crucial pillars in the edifice of modern physics. Probably, the only sure way to increase the yield of productive genius is to broaden the population base that is fertile. By this I mean to raise the level of scientific awareness among the billions of people who are now collected under the rubric - underdeveloped or Third World. Easily, this would represent a three-fold increase in the base from which, presumably by random process, genius arises. I must add the wry comment that other benefits would flow from this utopian proposal. How do we

know that the child drawing triangles in the dirt of an African village does not contain in his brain the capability of curing cancer or clarifying the mystery of senility?

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37. The creation of a healthy, productive VBR enterprise demands the effort of decades and involves all elements of the society in which the science is embedded. History teaches us of the rise and fall of great scientific nations. It is for scholars to say why science flowered in 16th Century Italy, 17th Century France or 19th Century England but it is also clear that the enterprise is fragile and once dismembered, it takes many decades to restore. Clearly the thirty year post WWII period has not been enough to restore Germany to the scientific greatness it had in the early part of this century.

A crucial aspect of VBR is graduate education. The difficulties which seemed to be posed here by new Federal policy is at least as serious as inadequate support of the research itself.

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Executive Director
ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Dr. Burton Richter
Technical Director
Stanford Linear Accelerator Center
Stanford, California 94305

Dear Dr. Richter:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. RICHTER

1. You stated that if there is a problem with the 50 megawatt (MW) klystrons, you have a fall-back position which is more complex and uses the existing 36-MW peak power tubes. If this fall-back position is adopted, what would be the impact on the cost of SLC?
2. Could you please elaborate a bit more on the advantages of SLC having polarized beams? Will LEP also have polarized beams?
3. What are the estimated costs of the SLC detectors, i.e., the Mark II Upgrade and the new SLD detector?
4. Can the Mark II detector be upgraded to be LEP-competitive?
5. What are SLAC's long-range plans? Do you see the current machines carrying you forward into the next century?

MINORITY QUESTIONS
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS
February 22, 1984

Dr. Richter

1. What is the cost of the modifications to the Mark II detectors?
2. What is the cost of the development of a new detector for the SLC?
3. Would a 4 year construction schedule be acceptable if more funding were to be provided for the development of new detectors?
4. SCAC promised to operate for 33 weeks in FY 1984 at a cost of $48 million. The request in FY 1985 requests $52.9 million in order to operate for only 30 weeks. Please explain.

March 14, 1984

SLAC MEMORANDUM

To: Harlan Watson

From: B. Richter

Subject: Response to Questions in Mr. Fuqua's Memo of February 28, 1984

---

1. This question asked the impact on the cost of the SLC if our fall-back position using the existing 36 MW peak-power tubes were adopted.

   Answer: The use of the existing tubes would cost us about $7 million more than the amount budgeted for the 50 MW tube option.

2. This question asked about the advantages of polarized beams and about LEP's ability to have polarized beams.

   Answer: The weak interactions are sensitive to the component of electron polarization along the beam's direction of motion. By varying the component of polarization along this direction of motion, certain processes can be turned on or off at will allowing considerably more sensitive tests of the theory than can be done in the absence of beam polarization. With the respect to LEP, there is a raging argument among the machine theorists as to whether any polarization will exist. I, personally, do not believe it will, and confidence in Europe in the existence of polarization at LEP is sufficiently low so that none of the necessary polarization manipulators are being included in the LEP construction project.

3. This question asks about the estimated costs of the SLC detectors.

   Answer: The Mark II upgrade is estimated to cost about $10 million and the new SLD detector is estimated to cost about $40 million.

4. This question asks whether the Mark II detector can be upgraded to be LEP competitive.

   Answer: SLAC's Experimental Program Advisory Committee, a nationally based committee set up to advise us on questions like this, examined this subject in great depth. Their conclusion was that none of the existing PEP detectors could be upgraded to be "LEP competitive."

5. This question asks about SLAC's long range plans, and whether we see the current machines carrying us forward into the next

century.

Answer: It is hard to look more than 10 years in the future in high energy physics for it is a rapidly changing science. On the basis of what we know now, we believe that the SLC will remain a frontier facility until sometime in the mid-1990's. How far beyond that time physicists will be interested in the answers provided by experiments in the SLC will depend on what we understand about weak interaction physics then. I should point out that our smallest storage ring facility, SPEAR, is still doing frontier research in its energy region more than 12 years after its turn-on.

In parallel with the construction of the SLC, we at SLAC are doing systems studies and some R&D on the very large linear colliders for which the SLC itself is intended to be a proof of principal. We believe it is already clear that such large machines can technically be built but the optimum configuration is not yet developed and the SLC itself has not run to show us whether we have understood all of the important problems. We should understand considerably more about large electron-positron machines in a few years and we will then start to plan future facilities at SLAC.

Minority Questions

1. This question asks about the cost of modifications to the Mark II detector.

   Answer: The Mark II upgrade is estimated to cost $10 million.

2. This question asks about the cost of the development of a new detector for the SLC.

   Answer: The new detector is estimated to cost about $40 million.

3. This question asks about the acceptability of a 4 year construction schedule if more funding were to be provided for the development of new detectors.

   Answer: We would much rather turn the SLC on at the end of 1986 using the upgraded Mark II detector for experimentation than to delay the project for a year with a higher rate of funding provided for a new detector. Given the amount of design work required for a new detector and the time required for the construction of some of its most sophisticated components, it is not likely that the new detector could be ready in 1987 in any event. A delay will simply lose us one year of experimentation.

4. This question asks about operations in FY 84 and FY 85.

   Answer: The present SLAC financial plan for FY 1984 contains $48.4 million for facility operations and will allow us to run for about 28 weeks. The budget submission for FY 85 requests

$52.9 million and with that funding we will operate for the same 28 weeks of high energy physics, and may also be able to provide 8 weeks of special running for nuclear physics experiments if funds are provided from that program. Thus, our estimate of costs for the same amount of high energy physics running is up by 9% in FY 85 over FY 84. This increase has two components to it. The first is general inflation and the second is the much faster than inflation, increase in the costs of power which I discussed in response to an earlier question. The Western Area Power Administration is raising its prices for public power by roughly 25% next year. This is the main reason for a cost increase for equal operations of 9% in a year when general inflation is at the 4 or 5% level.

BR:rt

B.R.

DON FUQUA (Fla.), Chairman

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Minority Staff Director

February 28, 1984

Dr. John P. Schiffer
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Dear Dr. Schiffer:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. SCHIFFER

1. Do the budget projections for the DOE/NSF programs in nuclear science through FY 1994 (in FY 1983 dollars) given on Figure IV.5-D on page 70 of the December 1983 Long Range Plan assume that the proposed 4-GeV electron accelerator will be constructed at a cost of $146.8 million and have an annual operating costs of $18.1 million? It now appears that the 4-GeV accelerator will be considerably more costly--perhaps as much as $225 million or more. What is the implication of this for the out-year budget projections and on the priority order of the recommendations made in the December 1983 Long Range Plan?

2. The NSAC held a two-day meeting last week (February 13 and February 14, 1984) here in Washington to consider, in part, facility reports from many of the major DOE and NSF nuclear physics research institutions. What were the major concerns expressed by the facility report presenters, and what were the concerns/issues expressed by NSAC?

3. The NSAC Instrumentation Subcommittee has recently submitted its draft recommendations to NSAC. What are these recommendations and what are the budgetary implications of these recommendations?

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439
Telephone 312/972- 4066

March 9, 1984

RECEIVED
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COMMITTEE ON SCIENCE
AND TECHNOLOGY

Congressman Donald Fuqua
Chairman
Committee on Science and Technology
U.S. House of Representatives
Suite 2321
Rayburn House Office Building
Washington, D.C. 20515

Dear Congressman Fuqua:

I appreciate your further interest and the opportunity to respond in somewhat more detail to your questions of February 28, 1984. To the first question:

> "Do the budget projections for the DOE/NSF programs in nuclear science through FY 1994 (in FY 1983 dollars) given on Figure IV.5-D on page 70 of the December 1983 Long Range Plan assume that the proposed 4-GeV electron accelerator will be constructed at a cost of $146.8 million and have an annual operating cost of $18.1 million? It now appears that the 4-GeV accelerator will be considerably more costly -- perhaps as much as $225 million or more. What is the implication of this for the out-year budget projections and on the priority order of the recommendations made in the December 1983 Long Range Plan?",

I would respond as follows:

The December 1983 Long Range Plan for Nuclear Science assumed the cost of the 4-GeV electron accelerator to be that in the report of the NSAC Panel on Electron Accelerator Facilities for the SURA proposal: $146.8 million dollars. This amount was arrived at by the Panel as an approximate estimate which reflected the construction costs quoted in the SURA proposal and additional contingency, R&D, and experimental equipment costs recommended by the Panel. The amount was in FY 1983 dollars and one may estimate reasonable escalation to bring this to about $185 million in actual dollars. The amount arrived at by the Panel clearly is not, and could not be expected to be, a refined cost estimate. An increase of up to twenty percent is not surprising -- a further increase, however, especially in view of the delays in getting this project started, would become cause for concern. I must emphasize that these matters were not discussed in any detail by our Committee nor were we privy to the detailed considerations that went into the 200-225 million dollar cost estimate in the President's budget.

The overall budget projection in Figure IV.5-D of our Long Range plan was in FY83 dollars. The construction and operating costs associated with the 4-GeV electron accelerator were estimates, valid to 20%, and the operating

U.S. Department of Energy The University of Chicago

costs were assumed to be incremental to the present total operating budget. The costs of the relativistic heavy-ion collider are even more approximate, since here the design specifications of an accelerator are still under active study.

The 200-225 million dollar range for the 4-GeV electron accelerator does not represent a major departure from our Plan and thus does not affect the priority order of the recommendations in the December 1983 Long Range Plan.

In answer to your second question:

> "The NSAC held a two-day meeting last week (February 13 and February 14, 1984) here in Washington to consider, in part, facility reports from many of the major DOE and NSF nuclear physics research institutions. What were the major concerns expressed by the facility report presenters, and what were the concerns/issues expressed by NSAC?",

I can report that the major concern expressed in both the facility reports and the subsequent discussion in NSAC is the fact that the operating and equipment budgets are insufficient for the task of adequate utilization of facilities. In the NSAC Long Range Plan, as well as earlier during 1983, our Committee recommended in the strongest possible terms a one-time real increase of $20 million in operating and equipment funds for the facilities that are now in existence or under construction. It was a matter of very serious concern at our meeting that the Operating Funds in the DOE budget for existing facilities showed only a 4% increase, which is a de facto decrease after escalation. Our concern was reiterated in the enclosed letter (Enclosure 1).

Finally, in answer to your third question:

> "The NSAC Instrumentation Subcommittee has recently submitted its draft recommendations to NSAC. What are these recommendations and what are the budgetary implications of these recommendations?",

I enclose the draft recommendations of the NSAC Instrumentation Subcommittee (Enclosure 2). The general tenor of these recommendations found wide support in NSAC and the budgetary implications are within the above recommendation for the one-time increase of $20 million dollars in operating and equipment funds. The need for development of instrumentation and for technical support is specifically discussed in the enclosed letter of February 20, 1984.

Please let me know if our Committee can be of any further assistance.

Sincerely yours,

John P. Schiffer
Chairman
DOE/NSF Nuclear Science Advisory Committee

JPS/bw

Encls:

Enclosure 1

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February 20, 1984

Dr. James E. Leiss
Associate Director for High
Energy and Nuclear Physics
Office of Energy Research
U.S. Department of Energy
ER-23 GTN
Washington, D.C. 20545

Dr. Marcel Bardon
Director, Division of Physics
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Gentlemen:

In the meeting of the Nuclear Science Advisory Committee on February 13 and 14, 1984, we discussed the FY 1985 Budget Submissions for Nuclear Science. The Committee is certainly very pleased at the impact of our past recommendations as reflected in the NSF budget for Nuclear Physics, and in seeing in the budget submission for the Department of Energy increases in the construction and capital equipment budgets, including initial funding for the electron accelerator at SURA.

In this letter I want to stress the need for implementing a major priority for our science: the initiative of $20 million in operating and equipment funds, first stated in our letter of April 29, 1983 that transmitted and endorsed the recommendation of our Subcommittee on Electron Accelerator Facilities. This recommendation was reiterated emphatically in our Long Range Plan of December 1983. Both of these statements are appended to this letter.

The Committee noted that beyond the new initiatives at SURA, the DOE operating funds in the proposed FY85 budget fall $6-8M short of the extremely tight FY84 levels after considering escalation. Our advice of 1983 thus needs to be strongly reiterated, that an adjustment in operating and equipment funds is required by our field to rebuild, after a decade of cutbacks and constraints.

Our Committee is very pleased and enthusiastic about the initiatives in the FY85 budget submission for new undertakings in facility construction, but it must note that the agencies must likewise encourage the drive to do research; the wherewithal to utilize the facility initiatives of the past few years; and see to it that the human resources for pursuing our objectives are strengthened and replenished.

The $20 million initiative is needed in a number of important areas.

Utilization of Facilities. Our present array of facilities have much very important and exciting research to carry out, yet they are utilized perhaps to only 50% of their full capacity. This is partly a consequence of the costs of electric power at the major power-intensive facilities, but perhaps even more that of the enforced economies in instrumentation, in upgrading and replacing accelerator control systems, and in very marginal staffing of operations, support personnel and user assistance that impacts most of our accelerators.

At our meeting this past week we heard reports on facilities for nuclear physics research that are currently under construction or were recently completed. We found that remarkable progress has been made toward achieving state-of-the-art capabilities in several key areas for new research over the last few years. However, it is a matter of great concern that the current level of the operating budget will severely hinder the utilization of these capabilities and the realization of their promise.

Development of Instrumentation

The technology of experimental physics, the development of the techniques of particle acceleration and detection are key elements of our science. Many applications have developed from work on instrumentation for basic nuclear research. Yet, as is pointed out by the NSAC Instrumentation Subcommittee, while pioneering work is still going on, the pace of activity in this has to be stepped up urgently. The direction of our research is tending to more complex experiments, requiring the development of often entirely new detection techniques and data collection systems. Our technical capabilities for such developments have been seriously weakened during the fiscal stringencies of the 1970s.

Training of Young Scientists. This is clearly a vital area for any science, both to ensure future progress and to train young people in the skills of high technology. As we had pointed out before in the report of our Manpower Subcommittee and the Subcommittee on University Training, the rate at which nuclear scientists are being trained will not be adequate to meet the country's needs within the decade. Even some of our strongest university groups are so constrained in their budgets that they have to turn away good prospective students, while for other promising students the attractiveness of science as a profession is reduced by the very limited resources. A small amount of support here can go a long way.

Technical Support for User Groups

Most nuclear physics user groups at universities do not have the resources to hire technical and engineering help. These groups must either become dependent for instrumentation, technical development, and planning on the facility where they are users, or an undue burden falls on students and research associates. While clearly some such work should properly be part of a training in nuclear physics, it would considerably strengthen university user groups to be able to hire their own technical staff, either engineers or scientists specializing in technical problems. The impact on developments of instrumentation, on the style and quality of research and on the attractiveness of doing research as a graduate student in the user mode could be considerable.

The impact of budget cutbacks over the past decade have been inhibiting and the danger of having a set of facilities without the vital resources in manpower and instrumentation is real. There are exciting and important research initiatives that need to be realized, new competitive ideas must be encouraged, and a signal has to be sent to young scientists and prospective scientists that in the United States a career in science is worth pursuing. The need to attract young people to an education in the high technology of basic science is all too apparent, and has an impact on our country far beyond the confines of basic science.

The Committee very much appreciates the fact that major new initiatives in construction have appeared in the FY85 budget submission. But we must also recommend in the strongest possible terms that the one-time real increase of $20 million in operating funds for Nuclear Science be given a very high priority by the Department of Energy as well as the National Science Foundation, and by the other branches of the Federal Government responsible for the funding of basic research. This is an essential component of our Long Range Plan and impacts our present and future abilities to face up to challenges and obligations.

Sincerely yours,

John P. Schiffer
Chairman,
Nuclear Science Advisory Committee

JPS/bw

P.S. From the letter of April 29, 1983:

"In recommending a major new facility, it is essential also to recommend measures to ensure the continued growth and vitality of the research community that will use it. What is said here applies not only to the electromagnetic physics community but to the nuclear physics community as a whole. Major facilities in the United States are seriously underutilized, operating because of budgetary constraints at a fraction of full capacity. Much of their instrumentation is in serious need of modernization.

Accordingly, in addition to incremental funding for the construction and operation of the new electron accelerator, there is an immediate need for a significant injection of support to maintain the strength and balance of the nuclear research program. This will require some $20 million per annum in incremental operating and equipment funds."

From the Long Range Plan for Nuclear Science, December 1983:

"The research program in nuclear physics, with the facilities in existence or under construction, faces many challenges and opportunities now. To address those opportunities, central to the vitality of our field, it is essential that the $20 million incremental adjustment in operating and equipment funds for the ongoing research program that we recommended earlier this year be forthcoming."

Enclosure 2

From draft report of NSAC Instrumentation Subcommittee

INSTRUMENTATION RECOMMENDATIONS

As a result of this committee's discussions and the general direction for nuclear physics laid out in the 1983 NSAC long-range plan, highest priority is placed on detector development. This high priority arises from the new directions being taken in nuclear physics. An effective effort in general detector development will require more involvement from the university community than has been the case in the past.

Therefore, as highest priority, we recommend increased support for detector research and development activity and invite vigorous university participation.

Searches for the physics arising from the composite nature of the nucleon, its modification in the nuclear interior and determination of the nuclear equation of state will challenge our intellectual and technical resources as never before. A strongly focussed effort by a large segment of the nuclear research community will be required if we are to be successful. Support in the form of specialized technical facilities such as test beams at user facilities and resources for necessary travel must be accessible to university user groups involved in detector development. It is also likely that the engineering capability of university user groups should be enhanced. Adequately carried out, this recommendation will improve the on campus technical capability of university nuclear physics research groups and provide attractive options for experimentally-inclined graduate students. There are several examples of desirable detector research to be found in the appendices of this report. For example, a clearly identified need exists for research leading to improved energy resolution from large liquid ionization chambers.

The high priority NSAC has accorded new accelerator facilities which produce beams of high energy CW electrons and relativistic heavy ions places unprecedented demands on detector and spectrometer systems. In particular, it is an urgent matter to construct appropriate detectors for the relativistic heavy-ion beams to handle and envisioned to be provided by the AGS in 1986.

> **Therefore, we recommend high priority be accorded the specification, design and construction of detector systems to exploit the physics potential of relativistic heavy ion beams.**

Focussed workshops with Federal agency support need to be initiated immediately to define the physics and arrive at detector specifications.

As experiments become more complex and data rates incease, our ability to perform these experiments becomes limited by the data acquisition and analysis computer systems. The computing resources needed for rapid data analysis continue to be significantly greater than was believed a few years ago. Analysis time can be at least 15 to 20 times longer than the data acquisition time, even for moderatly complex experiments. The next generation of detectors will place demands on analysis facilities at least an order of magnitude greater than those presently experienced.

> **We recommend support for development of computer systems with multiprocessor architectures especially suited to the task of analyzing event mode data from nuclear experiments.**

A reasonable goal is a factor of 20-100 increase in speed of analysis of multiparameter data over what presently exists. There is also a definite need for small-scale systems which could be widely replicated as well as for a smaller number of large systems. This is a frontier area for computing in general. By virtue of the kinds of experiments we do, we have a unique opportunity to be in the forefront of computer systems design.

Substantial improvements have been made in the intensity of polarized positive and negative ion beams in the past few years. In contrast, for polarized electron beams, relatively little development work is in progress to improve the intensity and polarization, although the potential for improvement of photoemissive sources is very good. Measurements of fundamental symmetries and nuclear structure using high-energy electron accelerators will benefit from polarized electron beams of higher intensity and polarization than are currently available.

We recommend a few development programs with the objective of providing polarized electron sources of high brightness and polarization.

Polarized nuclear targets will also be required for a number of measurements with electron and ion beams. Particularly interesting targets will be those with high hydrogen content, low sensitivity to radiation damage, and in some cases, special purpose low density as can be obtained with a polarized gas jet. Several new techniques involving cryogenics, atomic beams or optical pumping have been showing promise for these applications. These techniques may also be useful in providing more intense polarized ion beams.

We recommend a few development programs with the objective of providing polarized nuclear targets with high polarization and low sensitivity to radiation damage.

In the appendicies of this report one can find more detailed discussion of the state of nuclear instrumentation in a number of specialized areas. In these specialized reports several useful suggestions and recommendations are offered, but the concensus of the subcommittee for the highest priority actions are those listed above.

DON FUQUA (Fla.), Chairman

ROBERT A. ROE, N.J.
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JAMES H. SCHEUER, N.Y.
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HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Dr. Sam Austin, Director
Cyclotron Laboratory
Michigan State University
East Lansing, Michigan 48824

Dear Dr. Austin:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. AUSTIN

1. Do you feel that both the NSAC Panel on Electron Accelerator Facilities (i.e., the Bromley Panel) and its Technical Subpanel had sufficient time to come to a reasoned decision? To what extent did the Panel and Technical Subpanel feel pressured by the lack of time?

2. On page 4 of the Panel's report, it is stated that "the Panel was not unanimous in its voting." What were the major points of contention?

3. Was the Technical Subpanel unanimous in its recommendations and assessments of each of the proposals, and if not, what were the major points of contention?

4. The 1982 Barnes Panel recommended construction of a high-intensity, high-duty-factor variable electron beam facility able to achieve an electron energy of about 4 GeV. Other requirements were also specified. How well does the SURA design measure up to these requirements?

5. Why did the Panel not decide until nearly two months after its establishment that construction of a 4 GeV accelerator was its highest priority? What were the areas of disagreement?

6. Can you please detail the reasons why a CW accelerator is needed? What is the significance of the ability to perform coincidence experiments? What additional information does this type of experiment add versus the types of experiments that can be performed with a lower duty-cycle electron accelerator, such as exists at SLAC?

7. The Panel's Report notes that the 35 faculty positions, including five new Tenure Commonwealth professorships, pledged by SURA "weighed substantially in their favor." How does this offer of faculty positions address either the DOE charge to the Panel (as stated on p. 2 of the Report), or the decision criteria used (as listed on pages 4 and 5 of the Report)?

MICHIGAN STATE UNIVERSITY

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COMMITTEE ON SCIENCE
AND TECHNOLOGY

March 7, 1984

Mr. Don Fuqua, Chairman
House Committee on Science and Technology
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Fuqua:

I have enclosed my response to the questions addressed to me in your letter of February 28, 1984.

I would be pleased to respond to a request for further information should that be useful to you.

Sincerely,

SM Austin
Sam M. Austin
Research Director

SMA/tp

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RESPONSE TO QUESTIONS POSED
by the
SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS
of the
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

I appreciate this opportunity to respond to further questions of the Committee.

1. Do you feel that both the NSAC Panel on Electron Accelerator Facilities (i.e. the Bromley Panel) and its Technical Subpanel had sufficient time to come to a reasoned decision? To what extent did the Panel and Technical Subpanel feel pressured by the lack of time?

> The schedule of the Panel required that its members work intensively. However, in my opinion, the effort expended and the time allotted were adequate to permit a detailed examination of the technical issues, and to come to a "reasoned decision".

2. On page 4 of the Panel's report it is stated that "the Panel was not unanimous in its voting". What were the major points of contention?

> In answering this question, I paraphrase the comments on pp. 61 and 62 of the Panel's report which well summarize my view of the major issues. In general, different viewpoints followed from different relative weightings of the various decision criteria concerning both technical accelerator issues and other considerations. The major points were: whether,of the proposed accelerators capable of reaching an energy of 4 GeV, the SURA design was overall technically the most conservative; the importance of the fact that the SURA design possessed greater flexibility for expansion to higher energies and additional continuous beams; the importance of the committment of 35 faculty positions by SURA; and the advantages and disadvantages of an entirely new laboratory. The weighting of these and other(mainly less important) criteria by individual Panel members led to the choice of the SURA proposal.

3. Was the Technical Subpanel unanimous in its recommendations and assessment of each of the proposals, and if not, what were the major points of contention?

> No. The major points of discussion were the relative capabilities and technical conservatism of those designs capable of reaching an energy of 4 GeV.

4. The 1982 Barnes Panel recommended construction of a high-intensity, high - duty-factor variable(energy) electron beam facility able to achieve an electron energy of 4 GeV. Other requirements were also specified. How well does the SURA design measure up to these requirements?

The beam requirements necessary to perform the program envisioned in the Barnes' Panel Report are specified in Table 2 of that report. I believe the SURA facility meets the Minimal requirements presented there, and all the important items of the Special requirements needed for certain individual experiments. The stated beam current requirement of 150 microamperes, which might be useful for certain special experiments, may not be achieved at the onset of operation. However, the anticipated initial value of 120 microamperes should increase to about 240 microamperes as research and development on klystrons is carried out. The Panel considered the consequences of this situation; in my judgment, and the expressed judgment of the Panel, the lower initial beam currents "will not compromise the experimental programs".

5. Why did the Panel not decide until nearly two months after its establishment that construction of a 4 GeV accelerator was its highest priority? What were the areas of disagreement?

The Panel was charged to review and evaluate each of five proposed facilities "as a possible component of the overall program of basic nuclear research, and recommend the facility or combination of facilities which will best meet the United States needs for basic nuclear research with electromagnetic probes." This was to be within the context of earlier studies of these matters and our "own best scientific judgment." Since the facilities proposed had a variety of maximum energies, the choice of energy had great importance in our deliberations; we wished to hear the widest variety of opinions and to consider them carefully. Moreover, the care taken in this part of our considerations did not delay our parallel consideration of the technical aspects of the proposals. Hence, the procedure followed seems correct in hindsight as well as in foresight. The major area of discussion concerned the question of whether a lower energy facility would adequately address the most important scientific questions accessible to study with electromagnetic probes; the Panel concluded, without dissent, that a 4 GeV accelerator was required.

6. Can you please detail the reasons why a CW accelerator is needed? What is the significance of the ability to perform coincidence experiments? What additional information does this type of experiment add versus the types of experiments that can be performed with a lower duty cycle electron accelerator, such as exists at SLAC?

In order to obtain detailed information about the behavior of a nuclear system it is often necessary to show that several particles were emitted from the same nuclear system at the same time. Such measurements are called coincidence measurements. If the particles in the beam come in bunches, concentrated in time, (as in a low-duty-cycle accelerator) then during the beam bunch so many events occur that particles from two different nuclear systems may arrive at the detectors at almost the same time and be confused with a truly coincident event. Some coincidence measurements can nevertheless be done at low-duty-cycle machines, but they are of a limited sort, permitting one to study only a limited class of events. It is the experience in nuclear physics and the opinion of the Panel, in accord with the recommendations of several earlier studies referred to in my formal testimony, that a high-duty-cycle accelerator will be necessary to attack many of the most interesting problems accessible to study with electromagnetic probes. A detailed listing and assessment of those experiments requiring high duty cycle is given in the report of the Barnes Committee.

7. The Panel's Report notes that the 35 faculty positions, including five new Tenure Commonwealth professorships, pledged by SURA "weighed substantially in their favor." How does this offer of faculty positions address either the DOE charge to the Panel(as stated on p. 2 of the Report) , or the decision criteria used (as listed on pages 4 and 5 of the Report)?

Concerning the DOE charge, one of the requirements of a national program of basic nuclear research with electromagnetic probes is a flow of active young scientists who will perform this research. It is my opinion and the expressed opinion of the Panel, that the "combination of collaborating universities and new permanent positions in nuclear physics constitutes a very substantial increment in the total U.S. university involvement in nuclear physics and goes a long way toward providing assurance that there will be the continuing flow of active young scientists required to exploit fully the major new facility that we discuss herein." The offer affects a number of the decision criteria. For example: Educational potential: many young scientists will be trained as graduate students in the SURA institutions, meeting the manpower needs of the CEBAF facility as well as the nation's requirements for technically trained talent; Impact on the Electromagnetic Physics and Nuclear Physics Communities: see comments above; Institutional Support.

Sam M. Austin

SMAustin

Research Director
National Superconducting
Cyclotron Laboratory
Michigan State University
March 6, 1984

DON FUQUA (Fla.), Chairman

ROBERT A. ROE, N.J.
GEORGE E. BROWN, JR., CALIF.
JAMES H. SCHEUER, N.Y.
RICHARD L. OTTINGER, N.Y.
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TOM LEWIS, FLA.

HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Dr. Harry D. Holmgren
Department of Physics and Astronomy
University of Maryland
College Park, Maryland 20742

Dear Dr. Holmgren:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

Don Fuqua

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. HOLMGREN

1. You stated that your National Advisory Board (NAB) had met twice; most recently on January 30. What advice did you receive from the NAB at the most recent meeting? What were their concerns?

2. In SURA's initial proposal submitted to the DOE and NSF in 1980, the project's cost estimate was under $100 million. The Bromley Panel included additional contingencies, R&D, and equipment to raise the costs to just under $150 million. Now DOE, in its budget submissions estimates the project's cost to be in the range of $200 to $225 million. What are the reasons for these cost increases? What escalation rates are assumed?

3. What were the strengths and weaknesses of the Charlottesville and Blacksburg sites, as compared with the Newport News site?

MINORITY QUESTIONS
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS
February 22, 1984

Professor Holmgren:

1. When do you anticipate providing a firm cost estimate for the construction of CEBAF?

2. How soon do you expect to have a project cost estimate for the Continuous Electron Beam Accelerator Facility? What amount of the requested $7 million will be necessary to obtain that estimate?

SURA SOUTHEASTERN UNIVERSITIES RESEARCH ASSOCIATION, INC.

March 7, 1984

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COMMITTEE ON SCIENCE
AND TECHNOLOGY

Honorable Don Fuqua
U. S. House of Representatives
2269 Rayburn House Office Building
Washington, DC 20515

Dear Congressman Fuqua:

I wish to thank you for having given me the opportunity to testify before the Subcommittee on Energy Development and Applications. I am happy to respond to the additional questions that members of the Subcommittee have raised. The responses are enclosed.

Sincerely yours,
Harry D Holmgren
Harry D. Holmgren
President

HDH/jm
Enclosure

MAR 12 1984

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Charlottesville, VA 22901
(804) 924-6783

Response to Additional Questions from Members of the Subcommittee on Energy Developement & Applications

by

Harry D. Holmgren

Question 1. You stated that your National Advisory Board (NAB) had met twice; most recently on January 30. What advice did you receive from the NAB at the most recent meeting? What were their concerns?

Response: The primary advice that the CEBAF National Advisory Board (NAB) gave the SURA management was to appoint a permanent director of CEBAF as soon as possible. They also urged SURA to start the buildup of the CEBAF staff at Newport News, particularly key senior people. The NAB recommended that SURA could fill up to two of five Distinguished Professorships provided by the Commonwealth of Virginia even before a director is appointed. They recommended that the primary accelerator design effort be moved to the Newport News site in the near future.

Other recommendations of the NAB included the formation of a Technical Advisory Board consisting of four to five people who are knowledgeable in accelerator design and the appointment of a Program Advisory Committee after the director has been appointed and the Users' Organization has been formed. Many participants in our spectrometer workshops have advocated a second ring for use with internal polarized targets. The NAB agreed with the SURA management that such a ring should not be included in the present scope of the project.

The NAB was concerned about the delay in the staff buildup and the start of R&D work resulting from the delay in federal funding of R&D in FY 1984. Our ability to hire the necessary staff would be greatly facilitated if FY 1984 funds were available.

Question 2. In SURA's initial proposal submitted to the DOE and NSF in 1980, the project's cost estimate was under $100 million. The Bromley Panel included additional contingencies, R&D, and equipment to raise the costs to just under $150 million. Now DOE, in its budget submissions estimates the project's cost to be in the range of $200 to $225 million. What are the reasons for these cost increases? What escalation rates are assumed?

Response: The Bromley Panel's cost estimates were in 1983 dollars. The project cost in the range of $200 to 225 million in the DOE budget submission includes escalation of the cost to the year in which the construction takes place. The escalation has been greater than initially anticipated as a consequence of the delays of the project resulting from delays in the availability of R&D funds in FY 1984 and the slow construction start reflected in the FY 1985 budget request. The escalation rates used were taken from the Higher Physics Cost and Prices Changes of March 1983 prepared by the DOE High Energy Physics Program for the construction of complex accelerator facilities. Using 1983 as the base year, the rates are:

FY 1983	1.000
FY 1984	1.064
FY 1985	1.143
FY 1986	1.239
FY 1987	1.340
FY 1988	1.439
FY 1989	1.541
FY 1990	1.651

More detailed design studies and cost estimates, including vendor quotations, for both the accelerator and conventional construction have further refined our cost estimates over those in our 1982 proposal. Our 1982 proposal was used by the Bromley Panel as the basis for their cost estimates.

Question 3. What were the strengths and weaknesses of the Charlottesville and Blacksburg sites, as compared with the Newport News site?

Response: The primary advantages of the Newport News site over the sites at Charlottesville and Blacksburg are the greater accessibility of the site from throughout the U.S. by commercial airlines and the availability of the Virginia Associated Research Campus (VARC) and the former Space Radiation Effects Laboratory (SREL) buildings. The Newport News site is serviced by three airports: the Patrick Henry Airport, within three miles of the site, provides convenient commuter service to many East Coast cities; a major airport in Norfolk, less than 30 minutes drive by interstate, provides direct flights to cities throughout the Unites States; and the Richmond airport, approximately one hour by interstates, provides alternate connections. The number of flights and convenience of air travel to cities outside the Southeast is significantly less at Charlottesville and Roanoke, the closest commerical airport to Blacksburg.

The VARC building provides approximately 23,000 square feet of office and laboratory space. The immediate availability of the VARC building, which can be used in its present state, will expedite the early buildup of staff. A modest renovation of the SREL building will provide an additional 13,000 square feet of office and laboratory space and 40,000 square feet for shops and service facilities. The space in the SREL building can be made usable early in the project and will provide space for the testing of prototype accelerator components in the design stages of the project. No comparable space is immediately available at either the Charlottesville or Blacksburg sites.

The Norfolk/Newport News area has a larger pool of technical labor than the other two sites. The number of nearby shops, including those at NASA Langley and the Newport News Shipyards, is greater at Newport News.

The major strength of the Charlottesville site was its proximity to the University of Virginia, approximately 10 miles. The University has been a major contributor to the CEBAF project and the accelerator design group is currently located there. The major strength of the Blacksburg site was that it is contiguous to the campus of Virginia Polytechnic Institute and State University.

The SURA Site Committee and the SURA Board of Trustees carefully considered all relevant factors before reaffirming the Board's initial 1981 selection of the Newport News site. The members of the Site Committee were:

SURA Board Members:

Thomas Clegg (Chair), Professor of Physics, University of North Carolina
Robert Glaze, Vice President for Research, University of Alabama in Birmingham
Cameron Satterthwaite, Professor of Physics, Virginia Commonwealth University
Jay Burns, Chairman of the Department of Physics, Florida Institute of Technology

Outside Representatives:

Hermann Grunder, Associate Director, Lawrence Berkeley Laboratory
James Ball, Director of the Hollifield Accelerator Laboratory, Oak Ridge National Laboratory
Lawrence Cardman, Director of the Electron Accelerator Laborabory and Professor of Physics, University of Illinois.

Response to Minority Questions by Harry D. Holmgren

Question 1. When do you anticipate providing a firm cost estimate for the construction of CEBAF?

Response: SURA expects to establish a firm construction cost for CEBAF by early summer 1984, after the next Technical, Cost, Schedule and Management Review of the project by DOE scheduled in June 1984.

Question 2. How soon do you expect to have a project cost estimate for the Continuous Electron Beam Accelerator Facility? What amount of the requested $7 million will be necessary to obtain that estimate?

Response: SURA expects to establish a firm construction cost for CEBAF by early summer 1984 after the next Technical, Cost, Schedule and Management Review of the project by DOE scheduled in June 1984.

R&D funds during FY 1984 are important to help pay the cost of the effort needed to refine further the cost estimates and to incorporate suggestions made by the DOE in February 1984 Review. The continuing R&D effort in FY 1985, $5 million of the requested $7 million, is essential to continue detailed studies of the accelerator characteristics and in the development of prototypes of the more sophisticated accelerator components. The $2 million requested for construction in FY 1985 is required to start the design of long lead accelerator components, some of the A&E effort associated with conventional construction, and the partial renovation of the SREL building needed to house the design staff and to carry out tests of prototypes.

DON FUQUA (Fla.), Chairman

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ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Dr. James S. McCarthy
Department of Physics
University of Virginia
Charlottesville, Virginia 22903

Dear Dr. McCarthy:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic.

I would appreciate your responses to the hearing questions by March 9, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

DR. McCARTHY

1. What is the experimental basis for the choice of 4 GeV for the machine's energy? What is the probability that the machine's energy may be higher or lower than needed, and what would be the consequences?

2. You noted that the major development required for CEBAF is the production of the high-powered klystrons needed to drive the linac. What other developments are required? Are there any "showstoppers"?

3. What is the projected construction and development schedule to complete the facility?

4. You state that space at CEBAF is being reserved to accommodate a number of multipurpose storage rings if the demand arises. Has SURA given any consideration to constructing a synchrotron radiation light source at CEBAF? Do you intend to pursue this?

EDA

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UNIVERSITY OF VIRGINIA
MCCORMICK ROAD
CHARLOTTESVILLE, VIRGINIA
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MAR 9 1984
COMMITTEE ON SCIENCE
AND TECHNOLOGY

March 7, 1984

The Honorable Don Fuqua, Chairman
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Fuqua:

I wish to thank you for the opportunity to testify before your Subcommittee. I have enclosed the answers to the additional questions that Members of the Subcommittee requested. I hope that these are satisfactory and will be happy to supply additional information if necessary.

Sincerely,

James McCarthy

James McCarthy
Professor of Physics and
Acting Director of CEBAF

JM/skh

encl.

Response to Questions

J. S. McCarthy
University of Virginia

Question 1. What is the experimental basis for the choice of 4 GeV for the machine's energy? Waht is the probability that the machine's energy may be higher or lower than needed, and what would be the consequences?

Answer 1. The major emphasis on the energy regime of 4 GeV and greater is to enter a region where the electron interaction with nuclei begins to resolve the point-like quark currents. This differs significantly from the low energy region where the reactions are dominated by larger clusters within the nucleus, the nucleons and mesons. One of the most important areas of investigation for fundamental nuclear physics is observing this transition to the quark and gluon degree of freedom described by quantum chromodynamics (QCD). The capabilities of this accelerator will permit exploration of phenomena involving the coherent and quark confining mechanism of the underlying nuclear force. The experimental program will depend significantly on coincidence measurements and this in turn requires the electron beam to have a high duty factor. The electron energy is high enough so that measurements can reach high momentum transfer, at least 10 fm^{-1}, so that spatial resolution of 0.1 to 0.2 fm can be obtained. This very short distance region of the nucleon-nucleon force is where the traditional meson exchange description is expected to breakdown and a QCD description be required. In addition to high momentum transfer there must be enough energy transfer to the system to study the production of isobars, vector mesons, strange particles and the nuclear dynamics based upon the short distance effects of QCD. These requirements dictate an energy of at least 4 GeV to adequately investigate these important questions.

The present accelerator can operate in the energy range of 0.5 to 4.6 GeV, with reduced current above 4.1 GeV. Therefore it is the question of maximum energy that is most crucial in the accelerator design. The physics arguments that lead to the requirement of 4 GeV are based upon extensive experimental information. However, as with all basic research instruments that are designed to investigate unknown frontiers in science there is no absolute limit or standard. The SURA designers have incorporated into the accelerator design the ability to easily increase the energy and to expand the experimental facilities. The flexibility of the linac-storage ring design in these areas was a major reason for its selection over alternative concepts.

Question 2. You noted that the major development required for CEBAF is the production of the high-powered klystrons needed to drive the linac. What other developments are required? Are there any "showstoppers"?

Answer 2. The major items that require research and development have been evaluated for this accelerator and a separate proposal submitted to the Department of Energy for funds to complete the necessary prototype development. In addition to the production of high power klystrons, the other significant items are the high power pulsed modulators to supply the klystrons and the accelerating sections of the linac which must maintain the high average power. There are many other areas of development but these are all within the state of the art technology and require only minor modification. The modulators and accelerating sections are not at the same level of technical difficulty as the klystrons. It should be emphasized that there are no hard failure modes for this accelerator. It can reach its design energy with existing technology. If the klystron performance is not initially achieved the accelerator can operate at reduced current while development continues to achieve the final design goal of 240 μA at 4.1 GeV.

Question 3. What is the projected construction and development schedule to complete the facility?

Answer 3. The research and development schedule is based upon receiving $2M of funds for initiation of detailed design and prototype construction. The present schedule would then have all critical elements finished in mid-year FY-86 and acceptance tests completed in the third quarter of FY86. The construction schedule will require advanced engineering design and site work to be initiated in FY-85. Rehabilitation of existing structures and new support buildings will begin in FY-86 with a completion date in the third quarter of FY-87. Engineering and design of the conventional construction for the accelerator complex will be completed in FY-86. Construction will start on the accelerator housing in FY-87 and be completed by the second quarter of FY-88. Fabrication and installation of technical accelerator components will be taking place in FY-87, Fy-88 and part of FY-89. Facility tests and pre-operation will commence in FY-89, with full operation of the accelerator planned for FY-90.

Question 4. You state that space at CEBAF is being reserved to accommodate a number of multipurpose storage rings if the demand arises. Has SURA given any consideration to constructing a synchrotron radiation light source at CEBAF? Do you intend to pursue this?

Answer 4. SURA has considered the possibility of adding a synchrotron light source to CEBAF. A committee has been created to look at this possibility and is presently collecting information and listening to expressions of interest from scientists. Before any major development can occur the national situation regarding existing light sources, light sources expected to be in existence at the time of completion of CEBAF and national research needs must be carefully evaluated. The situation is not resolved; however, if there are scientific opportunities at such a light source and if it is consistent with the scientific planning in this country, SURA would initiate a development program.

DON FUQUA (Fla.), Chairman

ROBERT A. ROE, N.J.
GEORGE E. BROWN, JR., CALIF.
JAMES H. SCHEUER, N.Y.
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HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
DAVID S. JEFFERY
Minority Staff Director

February 28, 1984

Alvin W. Trivelpiece, Director
Office of Energy Research
U.S. Department of Energy
Washington, D.C. 20585

Dear Dr. Trivelpiece:

Thank you for your excellent testimony before the Subcommittee on Energy Development and Applications on February 22, 1984. Attached are some additional questions that Members of the Subcommittee would like you to answer, in order to supplement the record of the hearing on this topic. In addition, larger sets of questions based upon the fiscal year 1985 budget request for High Energy and Nuclear Physics are enclosed.

I would appreciate your responses to the hearing questions by March 9, 1984, and to the longer sets by March 23, 1984. If you have any questions regarding this request, please contact Dr. Harlan Watson of the EDA Subcommittee staff at (202) 225-4320.

Sincerely,

DON FUQUA
Chairman

DF:Hcw
attachment

QUESTIONS FOR DR. TRIVELPIECE

FY 1985 DOE Authorization for High Energy and Nuclear Physics

February 22, 1984

1. **To what extent does the commonality among the high energy and nuclear physics program plans of the U.S., Europe, Japan, and the Soviet Union provide a basis for international cooperation?**

   Answer: The commonality and universality of goals within the high energy and nuclear physics programs of the U.S., Europe, Japan, and the Soviet Union have provided and continue to provide a strong basis for international cooperation. With regard to Europe and Japan, this cooperation has involved free exchange of information and personnel on both formal and informal bases; cooperative research programs; reciprocal access to unique accelerator facilities and instrumentation; and information exchange on future plans in order to coordinate the development of major facilities. The hallmark of this cooperation is the frequent exchange of ideas and information in international forums with a healthy mixture of competition, cooperation, and mutual respect. Cooperation with the Soviet Union takes place under the auspices of the US/USSR Cooperative Program on Fundamental Properties of Matter. Scientists from each area participate in research on each other's facilities on the basis of the scientific merit of their proposals. The salient feature of the program plans of each of these regions is uniqueness. Each region has an agenda for progress which optimizes, within a world context, return on the investment of its resources.

2. **In the area of high energy physics, what facilities operating, under construction, or planned in Europe, Japan, and the Soviet Union complement, supplement or replicate U.S. facilities?**

   Answer: A table is attached providing the names, locations, and some of the characteristics of the world's major high energy physics accelerator facilities.

   Brookhaven National Laboratory's Alternating Gradient Synchrotron (AGS) and CERN's Proton Synchrotron (PS), as originally constructed and operated, were very similar machines. However, the PS now serves as an injector to CERN's higher energy facilities, and thus, the AGS is unique for physics research. Its energy coverage and special capabilities in its polarized proton beams and many high quality secondary beams are unique.

   The Serpukhov 76 GeV proton synchrotron covers an energy range between that of the AGS and those of SPS and Fermilab.

   The CERN Super Proton Synchrotron (SPS), at 400 GeV, operates in the same energy range as the Fermilab 400 GeV main ring formerly operated. Fermilab has now been upgraded through the Energy Saver and Tevatron programs to 800 GeV - 1000 GeV, opening up a new high energy fixed-target program with a variety of secondary beams for research opportunities quite different and unique from what is available anywhere else. When antiprotons become available for the Tevatron in two years, proton-antiproton collisions at 2000 GeV energy in the center of mass will be studied; truly a unique capability. The CERN S$\bar{P}$PS provides a proton-antiproton collider capability at 270 GeV x 270 GeV at low luminosity as an alternate operating mode of the SPS. There are plans to upgrade somewhat the energy and luminosity of the SPPS by 1986. Until Tevatron I comes into operation, S$\bar{P}$PS is a completely world-unique facility. DESY's DORIS II electron-positron collider has recently been upgraded to 7 GeV x 7 GeV and is now operating in a similar energy range to the CESR (8 GeV x 8 GeV) electron-positron collider at Cornell, because of the high importance and richness of the research associated with upsilon physics. The Stanford Linear Accelerator Center's (SLAC) Positron-Electron Project (PEP) and DESY's (PETRA) positron and electron collider, as originally designed and built, were very similar. However, PEP has focused on small cross section experiments requiring high luminosity at about 15 GeV x 15 GeV, while PETRA has upgraded its energy at considerable cost to 22.5 GeV per beam and focuses on the highest energies, primarily in its search for the top quark. The TRISTAN electron-positron collider, under construction at KEK in Japan, will provide 30 GeV x 30 GeV collisions at high luminosity. TRISTAN is scheduled to come into operation in 1986.

Although the Stanford Linear Collider (SLC) has the same energy goal for electron-positron collisions as Phase I of LEP at CERN (50 GeV x 50 GeV--this is expected to be a rich physics region for studies of the copious production of Z^0's), SLC and LEP are very different in overall purpose, conceptual design, and schedule. SLC will provide a full-scale accelerator R&D test of the concept of a linear collider, which is the only currently known practical way for future development of much higher energy electron-positron collision energies at an affordable cost. The SLC is scheduled to operate late in 1986, which is two years earlier than the LEP schedule. SLC also has unique capabilities for polarized beams and the ability to detect very short tracks because of the small size of the colliding beams. LEP has the unique capability of being able to extend its energy to as high as 130 GeV x 130 GeV for a Phase II.

The SLAC two-mile long linear electron accelerator is unique as a 20 - 50 GeV electron-positron fixed-target accelerator, as well as being an essential part of the SLC.

The UNK facility, under construction at Serpukhov in the Soviet Union, will provide a 3 TeV proton fixed-target capability and 3 TeV x 400 GeV proton-proton collisions in its first phase to be completed by the early 1990's. A subsequent second phase would provide 3 TeV x 3 TeV proton-proton collisions.

At DESY, construction has begun on a 30 GeV x 800 GeV electron-proton collider, Hadron-Electron Ring Anlage (HERA), planned for operation in 1988-89. Also, in Japan a 30 GeV x 300-400 GeV electron-proton collider is tentatively planned as a Phase II of TRISTAN.

The Superconducting Super Collider (SSC) being pursued by the U.S. is planned to provide a 20 TeV x 20 TeV high luminosity proton-proton collider for operation by 1994. This will be a world unique facility with unmatched capability to explore the TeV mass range where major breakthroughs in understanding are anticipated.

Table

Major High Energy Physics Accelerator Facilities in the World

Location	Laboratory (City)	Type of Machine	Accelerated Particle	Beam Energy (GeV)	Center-of-Mass Energy (GeV)	First Operation***	Status
Western Europe	CERN (Geneva, Switzerland)	Synchrotron(SPS)	p^*	400		1976	Operating
		and Storage Ring ($Sp\bar{p}S$)	$p\bar{p}$	270 x 270	540	1981	Operating
		Storage Ring (LEP)					
		Phase I	e^+e^-	50 x 50	100**	(1988)	Under constr.
		Phase II	e^+e^-	≤130 x 130	≤260**	—	Planned
	DESY (Hamburg, Germany)	Storage Ring (DORIS-II)	e^+e^-	7 x 7	14	1982	Operating
		Storage Ring (PETRA-II)	e^+e^-	22 x 22	44	1983	Operating
		Storage Rings (HERA)	e^-p	30 x 820	314	(1989)	Scheduled 1984 constr.
Japan	KEK (Tsukuba)	Synchrotron (KEK)	p^*	12		1976	Operating
		Storage Rings (TRISTAN)					
		Phase I	e^+e^-	>30 x 30	60-70**	(1986)	Under constr.
		Phase II	e^-p	30 x 400	173	—	Planned
China	Inst. of HEP (Beijing)	Storage Ring (BEPC)	e^+e^-	2.5 x 2.5	5	1987	Under constr.
USSR	IHEP (Serpukhov)	Synchrotron	p^*	76		1967	Operating
		Synchrotron & Storage Rings (UNK)					
		Phase I	p^*	3000		(1990)	Under constr.
			pp	400 x 3000	2,190**	(1990)	Under constr.
		Phase II	pp	3000 x 3000	6,000**	—	Planned
			$\bar{p}p$	3000 x 3000	6,000**	—	Planned
	Institute of Nuclear Physics (INP) (Novosibirsk)	Storage Ring (VEPP-IV)	e^+e^-	7 x 7	14**	1979	Operating
		(VAPP-IV)	pp	25 x 25	50**	(Unknown)	Unknown
U.S.	Brookhaven Nat'l Lab (Upton, NY)	Synchrotron (AGS)	p^*	30		1960	Operating
	Cornell U. (Ithaca, NY)	Storage Ring (CESR)	e^+e^-	8 x 8	16	1979	Operating
	Fermi Nat'l Accel Lab (Batavia, IL)	Synchrotron (TeV II)	p	1000*		1983	Operating
		Storage Ring (TeV I)	$p\bar{p}$	1000 x 1000	2,000	(1986)	Under constr.
	Stanford Linear Accel Center (Palo Alto, CA)	Linac	e^-, e^+	30, 20		1966	Operating
			e^-, e^+	50, 40		(1985)	Improvement in progress
		Storage Ring (SPEAR)	e^+e^-	4 x 4	8	1972	Operating
		Storage Ring (PEP)	e^+e^-	15 x 15	30	1980	Operating
		Linear Collider (SLC)	e^+e^-	50 x 50	100**	1986	Under constr.
	(Undetermined)	Storage Rings	pp	20000 x 20000	40,000**	(1994)	Planned

*Each fixed-target accelerator also has a number of secondary beams with a variety of particle types.
**The number given is a design goal, not measured value.
***Projected dates for future facilities shown in parentheses.

3. **In the area of nuclear physics, what facilities operating, under construction, or planned in Europe, Japan, and the Soviet Union complement, supplement or replicate U.S. facilities?**

Answer: The requested information is provided in the table below.

MAJOR FOREIGN FACILITIES FOR NUCLEAR PHYSICS RESEARCH

	Description	First Beam
MESON FACILITIES		
Cyclotrons		
SIN Swiss Institute for Nuclear Research Villigen, Switzerland	590 MeV protons, 100 microamperes	1974
	upgrade in progress for currents above 1000 microamperes	1986
TRIUMF (Tri Universities Meson Facility) Vancouver, Canada	520 MeV protons, 100 microamperes	1974
Linear Accelerators		
Institute for Nuclear Research Moscow, USSR	600 MeV protons, 1000 microamperes (includes pulse storage ring facility)	1985
HEAVY ION FACILITIES		
SIS 18 Institute for Heavy Ion Research Darmstadt, West Germany	1.9 GeV/n neon 0.9 GeV/n uranium	1990
	with pulse stretcher ring. 100%, DF 0.5 GeV/n neon 0.3 GeV/n uranium	
NUMATRON Institute for Nuclear Studies Tokyo, Japan	1.4 GeV/n neon 1.0 GeV/n uranium (partially funded)	1990
SPS CERN, European Organization for Nuclear Research Geneva, Switzerland	9-200 GeV/n oxygen	1986

	Description	First Beam
Cyclotrons		
VICKSI Hahn-Meitner Institute for Nuclear Research Berlin, Germany	K= 127 to 144 (6 MV electrostatic injector)	1977
Joint Institute for Nuclear Research Dubna, USSR	K=720 23 MeV/n iron	1980
GANIL Grand Accelerateur National d'Ions Lourds Caen, France	twin K=400 cyclotrons	1983
University of Milan Milan, Italy	K=800 superconducting	1985
Chalk River Nuclear Laboratory Chalk River, Canada	K=520 superconducting (tandem injector)	1985
RIKEN Institute for Physical and Chemical Research Tokyo, Japan	K=520 (linac injector)	1984
Lanzhou Institute of Modern Physics Lanzhou, China	K=450 (K=69 cyclotron injector)	1987
SARA Institute for Nuclear Science Grenoble, France	K=160 (K=90 cyclotron injector, ECR source)	1982
Linear Accelerators		
UNILAC Institute for Heavy Ion Research Darmstadt, West Germany	10 MeV/n uranium upgrade to 20 MeV/n	1975 1982
Electrostatic Machines		
Nuclear Structure Facility Daresbury, England	20 MV	1983
Japan Atomic Energy Research Institute Tokai, Japan	20 MV	1980
National Atomic Energy Commission Buenos Aires, Argentina	20 MV	1984

	Description	First Beam
ELECTRON FACILITIES		
Linear Accelerators		
ALS Nuclear Physics Department of Saclay Gif-sur-Yvette, France	750 MeV, 100 microamperes, 1% DF	1968
NIKHEF National Institute for Nuclear and High Energy Physics Amsterdam, Netherlands	500 MeV, 50 microamperes, 2.5% DF	1982
Tohoku-University Sendai, Japan	150 MeV, 1 microampere, 80% DF linac-stretcher ring	1981
University of Saskatchewan Saskatoon, Canada	300 MeV, 50 microamperes, 0.1% DF	1964
	with pulse stretcher ring 300 MeV, 70 microamperes, 80% DF	1986
University of Bonn Bonn, West Germany	with pulse stretcher ring 3.5 GeV, 1 microampere, 70% DF	1985
Microtrons		
MAMI University of Mainz Mainz, West Germany	175 MeV, 100 microamperes, 100% DF cascaded microtrons	1983
	800 MeV, 100 microamperes, cascaded microtrons	1987
University of Lund Lund, Sweden	pulsed microtron, 100 MeV, 40 microamperes, 0.1% DF	1980
	stretcher ring, 25 microamperes, 100% DF	1982
Technical University of Darmstadt Darmstadt, West Germany	130 MeV, 10 microamperes, 100% DF superconducting cavities, 3 passes	1985

	Description	First Beam
LIGHT ION FACILITIES		
Synchrotrons		
SATURNE II Nuclear Physics Department of Saclay Gif-sur-Yvette, France	2.5 GeV protons, polarized beam 1.1 GeV/n carbon, argon	1977 1984
SYNCHROPHASATRON Joint Institute for Nuclear Research Dubna, USSR	4 GeV protons 4 GeV/n carbon	1957
Cyclotrons		
CERN European Organization for Nuclear Research Geneva, Switzerland	600 MeV protons 86 MeV/n carbon	1957 1974
Nuclear Physics Institute Groningen, Netherlands	140 MeV alpha particles	1970
University of Uppsala Uppsala, Sweden	200 MeV protons, upgraded	1984
Leningrad Nuclear Physics Institute Gatchina, USSR	1 GeV protons	1967
Institute for Nuclear Physics Julich, West Germany	180 MeV alpha particles	1969
Research Center for Nuclear Physics Osaka, Japan	120 MeV alpha particles 215 MeV nitrogen	1974
National Accelerator Center Faure, South Africa	200 MeV protons 660 MeV argon, separated sector	1985
Storage Ring		
LEAR (Low Energy Antiproton Ring) CERN, European Center for Nuclear Research Geneva, Switzerland	antiprotons, 5.3 MeV to 1.3 GeV (stretcher ring with acceleration and deceleration capability)	1982

4. **When do you expect to have a reasonably good cost estimate and schedule for the Continuous Beam Electron Accelerator Facility (CEBAF) at Newport News, Virginia?**

Answer: Our present objective is determination of a reliable cost estimate and schedule for the Continuous Electron Beam Accelerator Facility (CEBAF) by July 1984. Office of Energy Research staff conducted a formal review of the CEBAF project on February 27 and 28, 1984. We plan another formal review in June 1984. In the intervening period, we and Oak Ridge Operations Office staff will maintain close contact with the CEBAF project.

5. **What is the status of the start-up of R&D and staffing for the Continuous Electron Beam Facility?**

Answer: With State of Virginia funds plus some money from member institutions, the Southeastern Universities Research Association (SURA) has supported a very limited amount of research and development (R&D) work by Professor McCarthy and his colleagues at the University of Virginia. On July 1, 1984, seventeen maintenance and service people now employed by the State of Virginia at the Virginia Associated Research Campus will be transferred to SURA. They will continue as State of Virginia employees. R&D and staff build up beyond these very low levels will require Federal funds. The Department has submitted a reprogramming request to Congress which would permit us to award $2.0 million in FY 1984 funds to SURA for R&D activities including development of an appropriate technical and manpower base for the CEBAF project.

6. **What is the status of the long-range plan for high energy physics?**

Answer: In the summer of 1983 there was a major change in direction of the U.S. high energy physics program with the Department's decision to terminate the ISABELLE/Colliding Beam Accelerator efforts at Brookhaven National Laboratory and to initiate preliminary R&D toward the Superconducting Super Collider (SSC). A new long-range plan for the U.S. high energy physics program is being developed as the course of action relative to the SSC and its role in the national program becomes more clearly defined.

A critical input for such a plan will be the results of the review and evaluation of the SSC reference design studies and preliminary cost estimate to be completed in the summer of 1984.

7. **How will the FY 1985 Superconducting Super Collider (SSC) funds be used?**

Answer: The FY 1985 funding, $20 million, will be used to continue cost reduction studies, evaluation of cost and design tradeoffs, and evaluation of alternate superconducting magnet concepts; to validate the assumptions of the reference designs; to initiate conceptual design studies for a cost/performance optimized accelerator facility, and to evaluate site requirements.

8. **What is your next decision point to the SSC and when will it be reached?**

Answer: The next major checkpoint for the Superconducting Super Collider (SSC) will occur this summer after the Department has reviewed and evaluated the reference design studies and preliminary cost estimate. The results of that evaluation will give us a basis to assess whether SSC, as presently conceived, can be achieved at an affordable cost.

9. **Do you intend to explore international cooperation for funding the SSC? How do you intend to do this?**

Answer: We certainly plan to pursue possible avenues to achieve international participation in funding and use of the Superconducting Super Collider (SSC). We already have very substantial international collaboration in high energy physics, including joint participation in the fabrication and funding of very large, expensive detector facilities and joint use of each area's unique research facilities. Joint participation in the construction of a new facility would require an extensive departure from the typical, present mode of cooperation in which each country builds and operates unique facilities and other countries participate and share in the research program using the facilities. New mechanisms of cooperation would have to be established for joint construction of a major facility. One forum for such discussions is the working groups associated with the series of meetings of the Versailles Economic Summit. Western Europe already has major long-term efforts of its own under way and is not a likely candidate for substantial participation in SSC. Dr. Keyworth and I plan to visit Japan later this month to have discussions with the Japanese, including the opportunity for participation in SSC.

10. **Explain how the so-called "LEP" facility at CERN could be modified to be a scaled-down version of the SSC.**

Answer: A major feature of the Large Electron Positron (LEP) project at CERN is a circular tunnel with a circumference of 27 kilometers. A ring of low field (0.3 Tesla) conventional magnets in this tunnel will contain the counter-rotating electron and positron colliding beams planned for LEP. The installation of one or two additional rings of high field superconducting magnets in the LEP tunnel, along with associated cryogenics and other supporting technical systems, could provide the capability for a high energy antiproton-proton or proton-proton collider at CERN. With the currently proven technology of 5-6 Tesla superconducting magnets, such a hadron collider would have a maximum energy of about 5 TeV per beam. With higher field (up to 10 Tesla) magnets which might be developed in the future, energies of about 9 TeV per beam would be possible.

11. **Is CERN exploring the possibility of doing a scaled-down SSC? In what time frame could they accomplish this? How does this affect our SSC plans?**

Answer: CERN is studying the possibility of installing superconducting magnets in the Large Electron Positron (LEP) tunnel for use as a hadron collider. The radius of the tunnel limits the energy of such a collider to somewhat less than 1 TeV per Tesla of magnetic guide field; so if 10 Tesla magnets could be developed and fabricated, CERN could achieve as much as 8-9 TeV per beam for hadron collisions. With currently proven technology of 5-6 Tesla magnets, about 5 TeV per beam could be achieved for hadron collisions.

The first phase of LEP is scheduled for operation in early 1989, and there is a commitment to operate it for electron-positron colliding beam physics for at least several years to do experiments with the four main detectors now being fabricated. Assuming, therefore, that installation of a hadron collider in the LEP tunnel could not begin before the early 1990's, first operation would not be earlier than the mid-1990's. This would be a substantial departure from the present CERN long-range plan which calls for upgrading the energy of the LEP electron-positron collider.

The primary emphasis of U.S. R&D and design work on the Superconducting Super Collider (SSC) will continue to focus on cost and performance optimization for a hadron collider of about 20 TeV per beam which would come into operation by 1994. Current European and Soviet projects discussed above cannot compete with the SSC.

12. Are there any other international facilities planned that might complement the SSC?

Answer: There are three committed major foreign facilities where construction was recently initiated. The Large Electron Positron (LEP) collider at CERN, the Hadron-Elektron-Ring-Anlage (HERA) electron-proton collider in West Germany, and the Soviet UNK facility. These facilities would indeed provide physics capabilities complementary to those of the Superconducting Super Collider (SSC). The first phase of LEP will provide a 50 GeV x 50 GeV capability, to be in operation in 1989, with a subsequent Phase II planned which would raise the energy to as high as 130 GeV x 130 GeV. HERA at Deutsches Elektronen Synchrotron (DESY) will provide 30 GeV x 820 GeV electron-proton collisions and will be in operation by 1990. The UNK facility at Serpukhov will, in its initial phase, provide a 3 TeV proton fixed-target capability and a 3 TeV x 400 GeV proton-proton colliding beam capability to be in operation in the early 1990's. A planned subsequent phase would provide a 3 TeV x 3 TeV proton-proton collider.

MINORITY QUESTIONS FOR DR. TRIVELPIECE

HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS

February 22. 1984

SSC

1. **Is the Department of Energy committed to the development of the superconducting Super Collider (SSC) ?**

   Answer: The Department, after evaluating the High Energy Physics Advisory Panel (HEPAP) recommendation to initiate work toward the Superconducting Super Collider (SSC), intends to carry out preliminary R&D for the SSC in FY 1984 and FY 1985. Before committing to the SSC, the Department wants to review and evaluate the reference design studies and preliminary cost estimate this summer to assure itself that an SSC-like project can be achieved at an affordable cost.

2. **Has the Department committed, in its FY85 request, to phase I of the project?**

   Answer: The FY 1985 budget request contains funding to continue preliminary R&D related to the Superconducting Super Collider (SSC).

3. **If the FY85 funds are not considered Phase I funds, do you still envision the need for a $150-$200 Million intense R&D program?**

   Answer: We envision the need for a total R&D program of $150-200 million before we could be ready to begin construction of a Superconducting Super Collider (SSC). In the total SSC R&D program, we need to pursue R&D studies for cost reduction and to develop a cost/performance optimized conceptual design and cost estimate, to examine site requirements and produce a site criteria document, to develop and demonstrate cost-saving design and fabrication techniques, and to conduct systems tests. The preliminary R&D studies in FY 1984, and those planned with the $20 million requested in FY 1985, will contribute to this overall effort.

4. **If an intense R&D phase is necessary, to lower the ultimate cost of the facility through the development of new technology, when will this phase begin and how will the FY85 funding affect the date for proceeding with the ultimate construction of the project?**

   Answer: R&D and other studies to develop cost-saving designs are already under way in FY 1984 and will continue in FY 1985. To maintain the planned schedule for the R&D, it is necessary to make technical decisions to narrow down the number of magnet options which are currently being considered. The selection of a given magnet option might result in a facility of higher than minimum cost. The FY 1985 SSC R&D funding level will control the amount of R&D data available to support the decision on reducing the number of magnet options. Since all of the magnet approaches are considered technically feasible, the risk of making the decision with a reduced supporting R&D data base is therefore more one of cost than of technical performance.

5. **The Superconducting Super Collider R&D program proposes to spend $20 million in FY 1985. How will this program be managed? By whom? Where? What is expected of this expenditure? Please provide to the Committee the overall plan, schedule, and funding rate for the program.**

Answer: The Department has asked Universities Research Association to undertake the responsibility of assisting the Department in the management of the R&D and conceptual design phase of the Superconducting Super Collider (SSC) by forming a team to integrate the SSC activities at the various locations into a cohesive national effort. The physical location for the SSC Integration Group has not yet been decided. The $20 million requested for FY 1985 will be used for R&D to continue cost reduction studies, evaluation of cost and design tradeoffs, and evaluation of alternate superconducting magnet concepts, to validate the assumptions of the reference designs; to initiate conceptual design studies for a cost/performance optimized accelerator facility; and to evaluate site requirements.

GENERAL

1. **The Operating Expenses for Nuclear Physics facilities have increased by about 7.4% on the average, and yet the facilities are to be operated at only 90% of FY84 levels, would you please explain why?**

Answer: Under Nuclear Physics Operating Expenses, an increase of $10.6 million is requested in FY 1985 over FY 1984. Of this increase, $3.0 million is required for research and development activities in support of the Continuous Electron Beam Accelerator Facility; $1.0 million is required for the first year of operation of the new injector at the Stanford Linear Accelerator Center; and $0.7 million is mandated by the Small Business Innovation Act of 1982 for small business innovation research work. Thus, only an increase of $5.9 million is available in FY 1985 for the base Nuclear Physics program which totaled $131.1 million in FY 1984. This 4.5% increase in FY 1985 over FY 1984 for the base program is less than the 8 to 9% escalation rates expected at our Nuclear Physics accelerator facilities. For example, at each of our two largest accelerator facilities, LAMPF and Bevalac, we expect 9 to 10% escalation rates when electric power costs are considered. From previous experience, we know that a 4 to 5% shortfall in operating expenses at a complex accelerator facility will require at least a 10% reduction in beam hours for research.

2. **What maximum expenditure over what period of time is acceptable to the High Energy Physics Advisory Panel and to DOE for the SSC program?**

Answer: The High Energy Physics Advisory Panel (HEPAP) recommended strongly that the Superconducting Super Collider (SSC) should be completed in the first half of the 1990's. Although HEPAP did consider a number of funding scenarios which could accommodate SSC, their recommendation did not provide a specific indication of their view of a maximum acceptable expenditure for SSC. The Department has under way reference design studies which will provide a good preliminary cost estimate this summer based on clearly stated, credible assumptions about R&D successes. Once we have a credible cost estimate for SSC which has been carefully evaluated, the Department will develop a long-range plan which assesses competing priorities and considers SSC as a part of a viable, total U.S. program for the next decade or so. I think it is premature at this time to discuss specific numbers.

3. **What is the total investment in the High Energy Physics program including facilities, capital equipment, and supporting plant? How much will be spent in FY 1984 to maintain those assets? How much is requested for FY 1985 to maintain these assets?**

Answer: The following tables tabulate the funding invested in each high energy physics facility through FY 1984.

Line Item Construction
($ in millions)

	Then Year$	Period	FY 1985$
Brookhaven National Laboratory			
AGS	$ 31.0	1957-60	$150
AGS Conversion	47.3	1966-71	172
SLAC			
Linac and Laboratory	114.0	1960-67	510
Computer Building	2.9	1974	7
PEP	78.0	1976-79	135
Substation	1.7	1978	3
SLC (TEC $112M)	32.0	1984-	34
Fermilab			
400 GeV and Laboratory	248.3	1968-74	763
Energy Saver	50.8	1979-84	70
Tevatron I (TEC $82M)	54.1	1981-	60
Tevatron II (TEC $49M)	37.0	1982-	41
	$697.1		$1,945

Capital Equipment Budgets*
($ in millions)

	Total for FY60-84 Period	
	Then Year$	FY85$
BNL	97.2	235
SLAC	97.8	261
Fermilab	217.8	403
Universities	53.0	106
Other**	177.0	493
	$642.8	$1498

* Except for the initial complement of secondary beam and detectors at new facilities, much of the capital equipment is used for replacement components and limited life items and does not contribute to expanded capital plant. The estimated current replacement value of equipment presently existing and still usable is less than $500 million.

** Includes funding for laboratory group experiments at the accelerator laboratories, and funding supplied in earlier years, for equipment needs at accelerators which have since been terminated for high energy physics.

The following tables indicate the PACE funding provided in FY 1984 and requested in FY 1985 to avoid obsolescence and to maintain these assets in cost effective and scientifically effective operation. These do not include the routine maintenance operations and costs which are covered under the operating budget.

Accelerator Improvement Projects
(Then Year $ in millions)

	Actual FY84	Request FY85
BNL	2.0	2.0
SLAC	1.9	2.7
Fermilab	5.1	5.3
	$9.0	$10.0

General Plant Projects
(Then Year $ in millions)

	Actual FY84	Request FY85
BNL*	3.2*	5.7*
SLAC	1.3	1.5
Fermilab	2.5	3.0
	$7.0	$10.2

* The high energy physics program has responsibility to provide for GPP needs of the entire Brookhaven National Laboratory. During recent years, on the average, 25-30 percent of the GPP funding has been used in support of the conventional facilities related directly to the high energy physics program.

4. **What is the total investment in the Nuclear Physics Program, including facilities, capital equipment, and supporting plant? How much will be spent in FY 1984 to maintain those assets? How much is requested in FY 1985 to maintain these assets?**

Answer: We estimate the replacement value of our Nuclear Physics facilities at $750 million in FY 1984 dollars. To maintain the physical and scientific viability of these facilities, we have requested $30.0 million in FY 1985 under Capital Equipment and Construction. An additional $9.0 million under Capital Equipment and Construction is requested for new capabilities -- the Continuous Electron Beam Accelerator Facility and the Tandem/AGS Heavy Ion Transfer Line projects. In FY 1984, $23.3 million has been appropriated under Nuclear Physics Capital Equipment and Construction to maintain the physical and scientific viability of existing facilities; an additional $1.7 million was appropriated for new capability at the Stanford Linear Accelerator Center.

5. **How are maintenance projects selected from all facility requests? To what extent does maintenance compete with new purchases?**

Answer: Projects are selected according to the following order of priorities:

1) those needed to assure the continuity of operations,

2) those needed to protect Government assets from possible loss, and

3) those which offer a high rate of return in cost savings, as compared to the project cost.

To implement these criteria, each facility maintenance request is reviewed by the appropriate personnel in the laboratory and by the Department. Consideration is given to the mean time between failures of the system in question, to possible obsolescence of the equipment or plant, to the impact on operations, and to personnel safety concerns such as radiation exposure. The cost of maintenance is compared to that of replacing the system with a new one, taking into account the anticipated future demand for the particular system.

At the laboratory and program planning levels, maintenance projects compete for available funds with needs for the purchase of new equipment and plant. In developing funding plans, the Department and its contractors attempt to optimize overall program productivity, including efficiency and reliability of operation, and scientific effectiveness.

6. **What projections or studies has the Department undertaken to analyze the power demands and costs associated with the operation of the accelerator facilities? What were the results?**

Answer: The Division of High Energy Physics, in collaboration with the Independent Cost Estimating Staff of the Department of Energy, analyzes electric power costs associated with the operation of accelerator facilities on a regular basis. The past electric power usage and cost are known and are available upon request. The future projections for electric power depend upon laboratory utilization scenarios that involve the use of existing facilities, the upgrade of facilities, the phase out of facilities, the operation of new facilities, the implementation of energy saving techniques, and stringencies in the high energy physics budget. The interplay of these various operating scenarios can change the total electric power substantially. For the Stanford Linear Accelerator Center (SLAC), which uses more than one source of electric power, the cost variation can be substantial depending on the source; for example, during FY 1983 SLAC used electric power from both the Western Area Power Administration (WAPA) and the Pacific Gas and Electric Company (PG&E). The average annual cost of the WAPA electricity to SLAC was $9.33 per Megawatt hour during FY 1983 while the average annual cost of the PG&E power was $41.09 per Megawatt hour for the same time period. Whenever SLAC exceeds its electricity allotment from WAPA, the Laboratory must either draw from the PG&E main or cease operations. The cost of using the same electric power each year changes not only from normal cost inflation but also through special contractual agreements with the utility. The laboratories have used sophisticated electric load shedding techniques, superconducting devices, maximizing of off-peak use, and computer controls to minimize the cost of electric power for several years. Consequently, the Data Resources, Incorporated projected cost changes for U.S. electric power as compiled in the January 31, 1984, tables (7.0 percent in 1984, 7.5 percent in 1985, 7.2 percent in 1986, 7.8 percent in 1987, 7.0 percent in 1988, 5.6 percent in 1989, and 6.4 percent in 1990) cannot be casually applied to electric power cost changes for high energy physics accelerator facilities. The U.S. accelerator facilities make major efforts to conserve power and have been very cost effective in the use of electric power for basic research in high energy physics.

In the Nuclear Physics program the two major users of electric power are the LAMPF facility at Los Alamos National Laboratory and the Bevalac facility at Lawrence Berkeley Laboratory. During the past year, the Division of Nuclear Physics has conducted a detailed examination of escalation rates for facility operations, including electric power costs, at LAMPF and Bevalac. At these two facilities, electric power rates are escalating at about 20% per year; the composite index for all other costs is increasing at 8 to 9% per year.

QUESTIONS CONCERNING THE DEPARTMENT OF ENERGY'S FY 1985 HIGH ENERGY PHYSICS BUDGET REQUEST

GENERAL

1. For the period FY 1981 - FY 1985, please identify, by budget number and by facility, that portion of the High Energy Physics funding going for the support of facilities, such as the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory.

Answer: The following table provides the requested information:

(Budget Authority in Thousands)

	Estimate* FY 1981	Estimate* FY 1982	Estimate* FY 1983	Estimate* FY 1984	Estimate* FY 1985
AGS					
Operating	$31,673	$31,247	$40,115	$44,710	$50,790
Equipment	2,050	2,350	2,575	3,200	4,100
Construction	1,730	1,610	2,043	2,360	4,050
Fermilab (Fixed Target Program)					
Operating	76,911	85,205	92,274	91,057	117,460
Equipment	15,777	14,733	16,800	16,550	20,600
Construction	22,100	18,240	24,960	21,500	20,300
Fermilab (Tevatron I)					
Operating	2,221	3,337	15,600	17,500	3,240
Equipment	1,223	3,717	6,800	9,700	13,000
Construction	2,000	14,100	18,000	20,000	21,300
SLAC (Fixed Target)					
Operating**	13,821	11,330	12,759	14,510	7,292
Equipment	591	663	734	220	217
Construction	1,013	1,621	2,240	2,194	2,391
SLAC (SPEAR)					
Operating**	10,926	12,578	12,442	12,368	17,252
Equipment	1,925	694	741	620	1,257
Construction	66	390	215	247	503
SLAC (PEP)					
Operating**	27,106	28,375	32,826	37,332	46,656
Equipment	3,497	2,930	3,528	2,255	1,426
Construction	164	848	2,761	759	1,306
SLAC (SLC)					
Operating	3,697	8,747	17,003	9,700	9,500
Equipment	637	2,263	1,118	3,800	8,000
Construction	1,707	908	315	32,000	60,500

* In responding to this question it must be recognized that neither the laboratory organizational and accounting structure nor the DOE budget structure accumulate costs by facility in precisely the manner of breakdown indicated in the question. The data given are, therefore, estimates based primarily on input from the laboratory.

** Includes allocated share of linear accelerator operating costs.

2. **For the period FY 1981 - FY 1985, please provide, by DOE laboratory, the amount of High Energy Physics funding going to DOE laboratories.**

Answer: See attached table for information on funding to DOE laboratories provided by the High Energy Physics Program.

High Energy Physics
DOE Laboratory Funding
(Obligations in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Ames Laboratory					
Operating	$ 665	$ 700	$ 735	$ 790	$ 850
Equipment	50	50	50	350	50
Argonne National Laboratory					
Operating	6,800	6,262	5,680	5,785	6,300
Equipment	500	400	575	765	600
Brookhaven National Laboratory					
Operating	47,490	52,800	61,950	63,011	66,600
Equipment	2,800	3,000	3,300	3,400	4,300
Construction	38,765	19,471	9,426	5,274	7,700
General Purpose Equip.	2,800	2,900	3,500	3,500	3,900
Fermi National Accelerator Laboratory					
Operating	79,132	88,542	107,874	113,157	124,700
Equipment	17,000	18,450	23,600	26,250	32,100
Construction	24,100	32,341	42,958	40,602	41,600
Lawrence Berkeley Laboratory					
Operating	12,677	12,040	14,145	16,860	17,650
Equipment	4,000	4,450	1,840	2,549	1,600
Lawrence Livermore National Laboratory					
Operating	0	0	61	0	0
Equipment	0	0	30	0	0

High Energy Physics
DOE Laboratory Funding
(Obligations in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Los Alamos National Laboratory					
Operating	200	285	635	720	780
Oak Ridge National Laboratory					
Operating	457	550	593	590	650
Equipment	37	50	50	30	50
Pacific Northwest Laboratory					
Operating	0	100	396	100	175
Equipment	0	0	95	0	0
Stanford Linear Accelerator Center					
Operating	55,620	61,275	75,298	74,160	81,950
Equipment	6,650	6,550	6,120	6,895	10,900
Construction	2,977	3,768	5,531	35,200	64,700

3. **For the period FY 1981 - FY 1985, please provide, by institution, the amount of High Energy Physics funding going to university researchers.**

Answer: The attached tables give the operating and equipment funding provided under university contracts and grants.

University Contract Funding
(Budget Authority in Thousands)

Operating	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Univ. of Alabama	$ 0	$ 0	$ 0	$ 25	$ 30
Univ. of Arizona	194	205	375	387	390
Boston University	0	0	56	65	70
Brandeis University	240	330	408	408	430
Brown University	696	773	1,005	1,014	1,090
Univ. of Ca.-Berkeley	37	88	102	115	125
Univ. of Ca.-Davis	617	660	845	945	1,025
Univ. of Ca.-Irvine	1,749	2,110	2,849	2,090	2,655
Univ. of Ca.-Los Angeles	587	647	955	1,005	1,090
Univ. of Ca.-Riverside	615	725	1,046	930	980
Univ. of Ca.-San Diego	560	535	600	630	650
Univ. of Ca.-Santa Barbara	475	609	803	993	1,080
Univ. of Ca.-Santa Cruz	440	506	575	606	665
Ca. Institute of Tech.	2,129	2,070	2,542	2,640	2,880
Carnegie Mellon Univ.	1,090	1,155	1,474	1,530	1,655
Univ. of Chicago	82	282	398	605	635
Univ. of Cincinnati	22	33	36	60	65

University Contract Funding
(Budget Authority in Thousands)

Operating (cont'd)	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Clarkson College of Tech.	0	0	0	46	55
Univ. of Colorado	525	705	1,072	910	1,220
Columbia University	568	715	815	880	950
Univ. of Connecticut	65	75	85	85	95
Cornell University	0	0	498	122	340
Duke University	340	345	391	450	490
Florida State Univ.	533	570	674	835	950
Univ. of Florida	145	150	225	293	325
Georgia Inst. of Tech.	52	62	65	70	75
Univ. of Georgia	18	29	31	35	40
Harvard Univ.	1,941	2,030	2,349	2,360	2,845
Univ. of Hawaii	877	930	1,180	1,330	1,450
Illinois Inst. Tech.	45	53	56	60	65
Univ. of Ill.-Chicago	0	0	15	15	20
Univ. of Illinois	1,610	1,680	1,827	2,000	2,160
Univ. of Indiana	836	890	1,072	1,185	1,290
Inst. for Adv. Study	270	340	380	460	520
Iowa State Univ.	53	55	70	75	85
John Hopkins Univ.	69	75	82	86	82
Univ. of Kansas	17	37	45	45	48
Lehigh University	62	66	69	73	80
Louisiana State Univ.	235	247	375	375	490
University of Maryland	1,128	1,405	1,765	2,235	2,790
Mass. Institute of Tech	3,776	3,993	4,557	4,590	5,360
Univ. of Massachusetts	155	130	85	155	170
Univ. of Miami	3	3	4	4	4
Michigan State Univ.	18	0	0	0	0
Univ. of Michigan	1,655	1,912	2,524	2,641	2,920
Univ. of Minnesota	500	591	795	1,525	1,925
Mount Holyoke College	21	10	30	35	37
Univ. of New Hampshire	50	55	65	0	0
Univ. of New Mexico	15	20	25	30	35
NY City Univ.-City College	125	220	370	85	145
NY City Univ.-York College	75	85	90	0	0
NY State Univ.-Albany	0	0	275	200	250
NY State Univ.-Binghamton	0	0	20	20	25
NY State Univ.-Stony Brook	242	265	210	205	660
Univ. of North Carolina	75	102	96	125	30
Northeastern Univ.	0	21	33	35	38
Northern Illinois Univ.	31	32	35	0	30
Northwestern Univ.	550	625	626	673	830
Univ. of Notre Dame	3	0	0	0	0
Ohio State Univ.	699	1,000	1,525	1,585	1,930
Oklahoma State Univ.	52	60	68	40	79
Univ. of Oklahoma	155	165	320	245	298
Univ. of Oregon	210	254	278	312	325
Univ. of Pennsylvania	2,150	2,325	2,759	2,870	3,155
Univ. of Pittsburgh	129	265	278	400	415
Princeton Univ.	1,460	1,560	1,777	1,870	2,130
Purdue Univ.	1,327	1,355	1,585	1,662	1,740
Rice Univ.	257	285	352	327	385

University Contract Funding
(Budget Authority in Thousands)

Operating	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Univ. of Rochester	1,140	1,264	1,600	1,685	2,085
Rockefeller Univ.	645	670	985	918	1,005
Rutgers Univ.	60	63	0	0	0
St. Bonaventure	16	0	0	0	0
San Francisco St. Univ.	28	40	60	65	70
South Carolina Univ.	65	83	88	90	95
Stanford University	221	295	465	450	490
Univ. of Southern Ca.	0	0	0	55	70
Syracuse University	170	226	240	250	260
Univ. of Tennessee	180	189	401	375	500
Texas A&M Univ.	100	200	200	410	455
Univ. of Texas	195	202	236	226	255
Tufts University	448	470	493	545	590
Vanderbilt Univ.	0	2	0	3	0
Va. Polytechnic Inst.	113	125	151	361	600
Univ. of Virginia	14	24	22	25	30
Univ. of Washington	503	546	685	770	850
Wash. Univ.-St. Louis	102	117	147	180	185
Wayne State Univ.	58	63	69	70	74
Univ. of Wisconsin	2,465	2,925	3,107	3,343	3,690
Yale University	2,045	1,969	2,404	2,360	2,620
New Junior Investigator Awards (In process)	0	0	0	400	500
Other (Deobligations)	0	- 1	-35	0	0
Total-Operating Expenses	$41,223	$45,992	$57,310	$60,288	$69,320
Equipment					
Brandeis Univ.	0	0	115	167	150
Brown Univ.	275	0	0	100	100
Univ. of Ca.-Irvine	0	371	0	0	400
Univ. of Ca.-Los Angeles	50	0	0	0	200
Univ. of Ca.-Riverside	0	0	200	160	0
Univ. of Ca.-Santa Cruz	50	50	40	40	0
Calif. Inst. of Tech.	0	0	315	250	500
Carnegie Mellon Univ.	0	0	55	47	50
Columbia University	0	0	365	250	250
Duke University	0	75	78	75	0
Harvard Univ.	350	450	429	514	800
Univ. of Illinois	50	0	425	176	200
Louisiana State Univ.	0	90	0	0	0
Univ. of Maryland	0	0	200	400	500
Mass. Inst. of Tech.	965	890	3,016	2,543	4,800
Univ. of Michigan	1,148	1,474	772	405	600
Univ. of Minnesota	0	85	195	0	500
Northwestern Univ.	0	120	120	100	0
Ohio State Univ.	0	0	220	250	200

University Contract Funding
(Budget Authority in Thousands)

Equipment (cont'd)	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Oklahoma St. Univ.	0	0	170	120	0
Univ. of Pennsylvania	505	495	450	150	300
Princeton Univ.	60	60	110	283	300
Purdue Univ.	150	200	180	110	200
Univ. of Rochester	60	50	0	300	500
Rockefeller Univ.	0	90	0	50	0
Va. Polytechnic Inst.	0	0	0	90	0
Univ. of Wisconsin	0	100	556	496	600
Yale University	0	250	329	330	300
Total-Capital Equipment	$3,663	$4,850	$8,340	$7,406	$11,450

4. **For the period FY 1981 - FY 1985, please provide, by organization, the amount of High Energy Physics funding going to non-DOE laboratory, non-university researchers.**

Answer: See attached table for funding to non-DOE laboratory, non-university researchers.

Funding for Non-DOE Laboratory and Non-University Contractors
(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Industrial Contractors					
General Electric	$ 0	$ 126	$ 0	$ 0	$ 0
Hadronic Press	75	40	0	0	0
Harry Diamond Lab	15	15	15	10	10
Hayes, Seay, Mattern & Mattern	61	0	0	0	0
Mathematical Sciences NW	0	0	134	145	185
Physical Dynamics	60	80	90	95	100
Small Business Innovation Res.	0	0	0*	2,053	3,812
Sterling Systems, Inc.	87	0	0	0	0
Supercon	100	0	200	200	0
Other	0	6	4	1	0
	$ 398	$ 267	$ 443	$ 2,504	$4,107

Funding for Non-DOE Laboratory and Non-University Contractors
(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Not for Profit Organizations					
Franklin Institute	$ 117	$ 135	$ 121	$ 130	$ 190
Houston Area Research Ctr.	0	0	0	1,600**	2,800
Int. Elec. & Elec. Eng.	4	0	7	0	0
La Jolla Inst.	0	0	5	0	0
Nat'l Acad. Sci.	0	0	80	0	0
ORAU	100	0	0	0	0
Smithsonian Inst.	0	44	105	122	108
URA-SSC Interim Management	0	0	0	600***	1,500
Wilson-Hill Assoc.	159	0	0	0	0
	$ 380	$ 179	$ 318	$2,452	$4,598
Other Federal Agencies					
GPO	$ 0	$ 3	$ 0	$ 0	$ 0
National Bureau of Standards	187	175	190	318	365
Nat'l Sci. Foundation	100	0	0	50	50
Naval Research Lab	0	0	140	187	205
	$ 287	$ 178	$ 330	$ 555	$ 620
Foreign					
IAEA	$ 53	$ 42	$ 0	$ 32	$ 55

* $617,000 transferred to Energy Supply R&D Appropriation for SBIR.

** Funding for seven months only.

*** URA SSC interim management activities did not begin until second half of the fiscal year.

5. **How much of the FY 1985 High Energy Physics budget request is for support of programs formerly funded by the DOE Nuclear Program or by any other DOE program?**

   Answer: The FY 1985 high energy physics budget request contains an estimate of $250,000 for support of a program at Cornell University to study collective acceleration with slow wave structures. This program was originally funded by the Advanced Energy Projects Sub-program within the Basic Energy Sciences Program. Upon determination of direct programmatic interest, the Division of High Energy Physics initiated its support of the program in FY 1982.

6. **What have been the major accomplishments of this program over the past five years?**

Answer: Progress in high energy physics for the years FY 1980-FY 1984 has been substantial. The Energy Saver at Fermilab, the world's first superconducting synchrotron, was completed and has already achieved the world record high energies for accelerated protons and extracted beams. The Positron-Electron Project (PEP) at the Stanford Linear Accelerator Center (SLAC) was completed, improved, and has produced substantial physics results during this period. At Brookhaven National Laboratory (BNL), Lawrence Berkeley Laboratory (LBL), and Fermi National Accelerator Laboratory (Fermilab) outstanding progress in R&D on and the development of successful superconducting magnets for pulsed operation in synchrotrons have been achieved. At BNL, the Alternating Gradient Synchrotron capabilities have been substantially improved in the areas of beam intensity and polarization. At SLAC, substantial R&D progress has been achieved on the Stanford Linear Collider which is now under construction and when completed, will produce electron-positron collisions at world record energies. At Fermilab, the Tevatron I collider is progressing toward its completion in FY 1986 and is expected to produce the world's highest energy proton-antiproton collisions.

In physics research, many exciting results have emerged during the last half decade. Lifetimes and other properties of long-lived heavy states of matter thought to contain heavy quarks have been measured directly at SLAC, Fermilab, and BNL. The long-sought particles which carry the weak nuclear force, called W and Z, were discovered at CERN, with U.S. participation. This result provides further confirmation of the unification of weak and electromagnetic forces. These experiments continue to produce exciting hints of future physics. Evidence against protons decaying as expected in the simplest theory which unifies the strong, weak, and electromagnetic interactions, is being accumulated in nonaccelerator experiments in deep mines in Ohio and Utah. These experiments now extend the minimum proton lifetime to close to 10^{32} years for the decay modes studied. Experiments at Fermilab have reduced limits on mass differences between different neutrino types. Evidence for gluons, thought to be the carriers of the strong nuclear force, was found in experiments at DESY in Hamburg, Germany, with U.S. participation. In addition, experiments at SLAC and BNL have found evidence for particles which may be made up entirely of the gluon fields. In a series of experiments at Fermilab and BNL the parameters describing quark "mixing" are being more precisely determined. These results bear on attempts to unify the strong, weak and electromagnetic forces and on understanding the observed phenomenon of microscopic violation of time-reversal symmetry. In a series of experiments at Cornell and DESY the properties of states of matter bearing the heaviest known quarks are being studied. These experiments establish masses and decay modes of the new particle states, and test the predictions of theoretical models. Quantum interference of the weak and electromagnetic forces was measured in experiments at SLAC and DESY, thus confirming theoretical expectations. Computations modeling the full theoretical content of modern gauge theories on a lattice of discrete space-time points, and utilizing and extending the capabilities of the largest computers, have produced many exciting results. In addition, some rigorous statements on particle masses have been proved which must hold true in the limit of continuous space-time, provided that limit exists. These results open a new field of theoretical investigations. Quantum electrodynamics, the theory of electromagnetism, has been further tested down to distances of less than 10^{-16} centimeters. Much progress has been made at the interface between high energy physics and astrophysics and cosmology, providing major new insights into the early beginnings of the Universe after the Big Bang.

7. For the period FY 1981 - FY 1985, how much funding has this program provided and is estimated to provide for the R&D of experimental devices/apparatus?

Answer: The following amounts have been provided through FY 1984 and are requested in FY 1985 for experimental facility R&D.

(Budget Authority in Thousands)

FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
$13,228	$13,100	$15,600	$15,580	$17,700

In addition to these funds, a small amount of the funding provided to university-based research groups is devoted to this purpose.

8. How does the research funded by the High Energy Physics program differ, complement, supplement, or overlap high energy physics research funded by any other parts of DOE, as well as by other agencies such as the National Science Foundation?

Answer: Other parts of DOE do not provide funds for high energy physics research. However, the advanced technology development carried out in the high energy physics program is the forefront variety and has impacted or supplemented other DOE programs in the past and can be expected to continue to do so. High energy physics, for example, has done pioneering work and continues to do forefront work in applied superconductivity, especially in the magnet technology and cryogenic systems areas. Such work has been of importance to such diverse DOE programs as magnetic fusion energy, inertial fusion, energy storage, nuclear physics, electric energy systems, and materials sciences.

The National Science Foundation (NSF) research programs supporting experimental particle physics and theoretical elementary particle physics complement and supplement, but do not overlap those of the DOE high energy physics program. The NSF supports the Cornell Synchrotron Laboratory whose 8 GeV x 8 GeV electron-positron colliding beam facility complements the capabilities of the DOE's lower energy (4 GeV x 4 GeV) Stanford Positron Electron Asymmetric Ring (SPEAR) and higher energy (15 GeV x 15 GeV) Positron Electron Project (PEP) facilities at SLAC. The Cornell facility is used by DOE and NSF-supported experimental accelerator user groups. Just as for the DOE-supported accelerator and colliding beam high energy physics facilities at Brookhaven National Laboratory, Stanford Linear Accelerator Center, and Fermi National Accelerator Laboratory, this Cornell facility is available to qualified users on the basis of scientific merit of their proposals, independent of their source of support. The DOE and NSF university programs support similar types of work, but complement each other. There is no direct overlap of funding for a given university group. There is good coordination between DOE and NSF to ensure that there is no overlap of support and to ensure proper coordination of large collaboration experiments which involve users some of whom are supported by DOE and some by NSF.

9. What types of formal and informal advisory groups are employed to assure that the program is of high quality and coordinated with the research carried out at other agencies? If any formal advisory groups exist, please define the role of each, and provide a listing of the current membership.

Answer: The High Energy Physics Advisory Panel (HEPAP) is a formally chartered Federal advisory committee which provides advice on a continuing basis on the National high energy physics program to the Secretary of Energy through the Director of Energy Research. The Panel meets approximately five times a year. Members are selected to provide a balance among expertise, institutional affiliation and geographical location, and are charged to act in the interest of the national program and not in the interest of their home institutions. The membership list for calendar year 1984 is attached. Meetings are always attended and participated in fully by National Science Foundation (NSF) staff, who also are consulted on the selection of the HEPAP Chairman and membership, setting up HEPAP subpanels, and other matters of programmatic interest.

In addition, special ad-hoc subpanels, reporting through the parent Panel have been formed and charged to study more specific problems facing the program. Notable among these are the series of new facilities subpanels which met in 1974, 1975, 1977, 1980 and 1983 and the Subpanel on Long Range Planning 1981-1982 which were charged with assessing the total national program. All of these issued reports which have significantly influenced the quality and direction of U.S. high energy physics. Most recently, the HEPAP Subpanel on Advanced Accelerator R&D was formed to advise DOE on early R&D activities related to Superconducting Super Collider (SSC).

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10. What is the current rate of Ph.D. production in the high energy physics?

Answer: We do not have reliable statistics specifically on Ph.D. production. We estimate the Ph.D. production rate to be about 150 per year.

11. What is the average cost to produce a Ph.D. in this field?

Answer: The average cost to DOE for direct support of a graduate student during his participation in DOE-supported research is estimated to be in the range of $15,000 per year. This includes the salary, and fringe benefits for the student and the appropriate overhead expenses. For students involved in experimental research this estimate does not include any of the costs of the experiment since the primary purpose of the experiments is scientific research and not training. In addition, it is very difficult to decide what fraction of the costs of the experiment should be allocated to the student.

12. Has the number of high energy physics researchers supported by this program been increasing, stable, or decreasing over the past five years? What change will occur given the FY 1985 budget request?

Answer: The total number of Ph.D. level physicists supported under the DOE high energy physics program has been increasing slowly over the past five years from 1400 in FY 1980 to about 1500 in FY 1984. The FY 1985 budget request will provide for about 1525 physicists.

13. What is the average annual cost per year to this program to support a high energy physics researcher?

Answer: The average cost per year to support a high energy physics researcher during the FY 1980 - 1984 period in operating and capital equipment expenditures was about $160,000 if one includes both Ph.D. level and graduate student researchers and about $225,000 if only Ph.D. level researchers, are included.

14. **How much has the High Energy Physics Program contributed to the support of DOE's Small Business Innovative Research (SBIR) Program for FY 1983? How much is estimated for FY 1984 and FY 1985? How was this assessment determined?**

Answer: In FY 1983 the high energy physics program contributed $617,000 to the support of DOE's Small Business Innovative Research (SBIR) program. It is estimated that high energy physics funds amounting to $2,053,000 in FY 1984 and $3,812,000 in FY 1985 will be used in support of the SBIR program. These amounts are determined pursuant to P.L. 97-219, which established the SBIR program and represent 0.2%, 0.6% and 1.0% respectively of the FY 1983, FY 1984 and FY 1985 HEP operating expense funding.

A. HOLIFIELD TABLES

1. **The January 31, 1984 "Holifield Tables" indicate that the IRB Fiscal Year 1985 budget request for the High Energy Physics (HEP) program totalled $586,000,000, including $414,500,000 for operating expenses and $171,500,000 for plant and capital equipment (PACE). According to these Tables, the Department's FY 1985 submission to OMB for the program totalled $558,500,000, including $384,800,000 for operating expenses and $173,700,000 for plant and capital equipment. What are the specific differences between these two budgets?**

Answer: The following table indicates the changes from the Internal Review Budget request to the OMB request.

(Budget Authority in Thousands)

	FY 1985 IRB Request	FY 1985 OMB Request	Change
Physics Research			
Operating Expenses	$114,700	$113,300	-$1,400
Facility Operations			
Operating Expenses	192,800	182,500	-10,300
Capital Equipment	66,000	66,000	-
Construction	105,500	107,700	+ 2,200
Subtotal	364,300	356,200	- 8,100
High Energy Tech.			
Operating Expenses	107,000	89,000	-18,000
Total	$586,000	$558,500	-$27,500

The reductions in Facility Operations (-$10,300,000) and Physics Research Operating (-$1,400,000) Expenses reduce the average facility utilization level from the 65-70 percent range to about 55 percent.

The change in construction is a $2,200,000 increment for General Plant Projects at Brookhaven National Laboratory as part of the Department's initiative to correct serious deficiencies in the condition of the plant facilities which have accumulated over the years at the national laboratories.

The change in High Energy Technology (-$18,000,000) reduces the level of R&D related to the Superconducting Super Collider.

2. **As noted in question 1 above, the Holifield Tables indicated that the OMB FY 1985 budget request for the HEP program totalled $558,500,000, including $384,800,000 for operating expenses and $173,700,000 for PACE. The FY 1985 Congressional request for HEP totalled $561,000,000, including $381,600,000 for operating expenses and $179,400,000 for PACE. What are the specific differences between these two budgets?**

   Answer: The following table indicates the changes from the OMB request to the Congressional request.

(Budget Authority in Thousands)

	FY 1985 OMB Request	FY 1985 Congressional Request	Change
Physics Research			
Operating Expenses	$113,300	$107,700	-$5,600
Facility Operations			
Operating Expenses	182,500	182,100	-400
Capital Equipment	66,000	65,400	-600
Construction	107,700	114,000	+6,300
Subtotal	356,200	361,500	+5,300
High Energy Tech.			
Operating Expenses	89,000	91,800	+2,800
Total	$558,500	$561,000	+$2,500

The changes in Capital Equipment (-$600,000) and in Operating Expenses for the Physics Research (-$5,600,000) and Facility Operations (-$400,000) Subprograms are to help make possible the increases discussed below within funding available to the program.

The change in Construction reflects an additional $7,000,000 for Stanford Linear Collider construction to maintain the planned three-year construction schedule and a reduction of $700,000 in Tevatron I construction.

The change in High Energy Technology (+$2,800,000) is to meet increased needs for R&D in support of on-going construction projects and for long-range R&D.

3. **Given the information in questions 1 and 2 above, what are the specific differences between the Department's FY 1985 IRB and the Congressional Request budgets for HEP?**

   Answer: The following table indicates the changes from the Internal Review report to the Congressional request.

(Budget Authority in Thousands)

	FY 1985 IRB Request	FY 1985 Congressional Request	Change
Physics Research			
Operating Expenses	$114,700	$107,700	$-7,000
Facility Operations			
Operating Expenses	192,800	182,100	-10,700
Capital Equipment	66,000	65,400	-600
Construction	105,500	114,000	+8,500
Subtotal	364,300	361,500	+2,800
High Energy Tech.			
Operating Expenses	107,000	91,800	-15,200
Total	$586,000	$561,000	-$25,000

A reduction of $10,700,000 in Facility Operations (Operating Expenses) and $7,000,000 Physics Research reduce the average facility utilization level from the 65-70 percent range to a level somewhat below 55 percent.

The change in construction includes: a $2,200,000 increment for GPP at BNL as part of the Department's initiative to correct serious deficiencies in the condition of the plant facilities which have accumulated over the years at the National laboratories; an additional $7,000,000 for SLC construction to maintain the planned three year construction schedule; and a reduction of $700,000 in Tevatron I construction.

The reduction of $15,200,000 in High Energy Technology reduces the level of R&D related to the SSC and meets increased needs for R&D in support of on-going construction projects and for long range R&D.

The changes in Capital Equipment (-$600,000) and the other changes in Operating Expenses for the Physics Research (-$7,000,000) and Facility Operations (-$10,700,000) subprograms are to help make possible the increases discussed above within funding available to the program.

B. MANAGEMENT INITIATIVES

4. According to the HEP budget justification (Congressional Budget Request, FY 1985, Volume 4, p. 27), the FY 1985 HEP budget request of $561,000,600 reflects $4,000,000 for savings resulting from management initiatives in the area of administrative processes/ field structure. What specific initiatives will result in these savings?

Answer: This management initiative is one of several initiatives which reflect the first implementation efforts of the DOE with regard to recommendations contained in various studies of departmental operations, including the President's Private Sector Survey on Cost Control (The Grace Commission) and the Federal Laboratory Panel of the White House Science Council (The Packard Report), as well as the Administration's program for improved management systems known as Reform 88.

The $4,000,000 in the HEP program represents savings in FY 1985 resulting from improved management of government owned, contractor operated (GOCO) facilities. This initiative involves improved utilization of private sector business practices by GOCO contractors through reduced procedural controls and heightened reliance on policy issuances and performance evaluation by the DOE Operations Offices. Cost initiatives for improved GOCO performance and reduction in reporting detail will lead to DOE management oversight at a higher level and to improved opportunities for innovation and implementation of new management processes by GOCO contractors. These savings will occur at all eight DOE operations offices and major contractors.

5. **Who will determine how these specific initiatives result in these savings?**

Answer: These initiatives will involve a wide variety of activities including a thorough examination of reporting requirements and reductions in those requirements and a thorough examination of procedural requirements levied on our contractors in such areas of achievements of socioeconomic procurement goals, management of subcontractor activities, program and management planning activities and others. In each case the principal staff or program office responsible for the activity being examined will be required to identify savings opportunities and initiate the actions to implement those activities. For example: reduction in procurement reporting requirements would be directed by the Procurement Office, reduction in ADP reporting by the Office of ADP Management and so forth. The overall effort will be coordinated and results will be assessed by the Assistant Secretary for Management and Administration.

6. **How will these savings be apportioned among the DOE Operations Offices, laboratories, and other contractors?**

Answer: All field offices and GOCO contractors will be expected to contribute efforts to achieve these savings. The impact on any individual organization will depend upon our assessment of the collective affect of eliminating or consolidating reporting requirements or simplifying procedures. For example: if a particular organization has estimated that meeting a particular reporting requirement requires four staff years of effort and that requirement is eliminated, we would expect the organization in question could reduce their overhead staffing by four staff years. While the data for making these estimates are not precise we believe it is sufficient to arrive at a reasonable basis to allocate the resultant savings without adverse impact on programmatic activities.

C. FACILITIES

1. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to each facility supported totally or partially by the High Energy Physics program, including the following: (i) Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS), (ii) Fermi National Accelerator Laboratory (Fermilab) 400 GeV Fixed-Target Program, (iii) Fermilab Energy Saver,**

(iv) Fermilab Tevatron I, (v) Fermilab Tevatron II, (vi) Stanford Linear Accelerator Center (SLAC) 32-GeV Linear Electron Accelerator Fixed-Target Program (vii) SLAC Positron-Electron Asymmetric Ring (SPEAR), (viii) SLAC Positron-Electron Project (PEP), and (ix) the SLAC Linear Collider (SLC). Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The requested information follows:

(i) Brookhaven National Laboratory Alternating Gradient Synchrotron

This information is provided in response to Question C-1.1.6.

(ii) Fermi National Accelerator Laboratory (Fermilab) 400 GeV Fixed-Target Program

The information is provided in the table below.

In the responses to this question, and to questions (iii) and (v), it must be recognized that the 400 GeV, Energy Saver and Tevatron II programs are closely linked parts of an evolving fixed target research capability at Fermilab. Until the end of FY 1982, there was a 400 GeV fixed target program using the main ring synchrotron; beginning in FY 1986 there will be a full Tevatron II 1000 GeV fixed target program at Fermilab; the period from FY 1983 to FY 1986 is a transition period. In this period it is difficult to precisely allocate costs to one facility or another and neither the DOE or Fermilab systems track costs in precisely this manner. For these Fermilab tabulations we have allocated In-house Research, Operations, Accelerator Improvements, and General Plant Projects entirely to Energy Saver in FY 1983 and FY 1984, and to Tevatron II in FY 1985 when 1000 GeV operation is expected.

(ii) Fermilab 400 GeV Fixed-Target Program

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
Operating	$57,173	$66,383	$ ---	$ ---	$ ---
In-House Research	5,999	6,252	---	---	---
Operations	50,153	59,150	---	---	---
Other Operating Expenses	1,021	981	---	---	---
Capital Equipment	15,255	13,099	---	---	---

	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
Plant	5,600	6,940	---	---	---
Accel. Improv.	3,400	3,900	---	---	---
General Plant	1,400	1,840	---	---	---
In-House Energy Management	800	1,200	---	---	---
Total	$78,018	$86,422	$ ---	$ ---	$ ---

(iii) Fermilab Energy Saver

The information is provided in the table below:

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
Operation	$17,863	$15,317	$89,515	$88,222	$ ---
In-house Research	---	---	8,542	9,407	---
Operations	---	---	68,300	75,100	---
Other Operating Expenses	17,863	15,317	12,673	3,715	---
Capital Equipment	---	---	---	---	---
Plant	17,300	6,500	7,860	8,500	---
Energy Saver	17,300	6,500	---	---	---
Accel. Improvment	---	---	4,500	5,100	---
General Plant	---	---	2,460	2,500	---
In-House Energy Management	---	---	900	900	---
Total	$35,163	$21,817	$97,375	$97,322	$ ---

(iv) Fermilab Tevatron I

The information is provided in the table below:

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
Operating	$ 2,221	$ 3,337	$15,600	$17,500	$ 3,240
Other Operating Expenses	2,221	3,337	15,600	17,500	3,240
Capital Equipment	1,223	3,717	6,800	9,700	13,000
Plant	2,000	14,100	18,000	20,000	21,300
Tevatron I	2,000	14,100	18,000	20,000	21,300
Total	$ 5,454	$21,154	$40,400	$47,200	$37,540

(v) Fermilab Tevatron II

The information is provided in the table below:

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
Operating	$ 1,875	$ 3,505	$ 2,759	$ 2,835	$117,460
In-House Research	---	---	---	---	10,000
Operations	---	---	---	---	88,700
Other Operating Expenses	1,875	3,505	2,759	2,835	18,760
Capital Equipment	522	1,634	16,800	16,550	19,100
Plant	---	6,000	18,000	13,000	20,300
Tevatron II	---	6,000	18,000	13,000	12,000
Accel. Improvement	---	---	---	---	5,300
Gen. Plant Project	---	---	---	---	3.000
Total	$ 2,397	$11,139	$37,559	$32,385	$156,860

(vi) Stanford Linear Accelerator Center (SLAC) 32 GeV Linear Accelerator Fixed Target Program

This information is provided in response to Question C-3.1.4.

In responding to questions which require the breakdown of SLAC funding by facility, it must be recognized that neither the SLAC organizational and accounting structure nor the DOE budget structure accumulate costs in precisely this manner. The data given are, therefore, estimates based primarily on input from SLAC.

(vii) SLAC Positron-Electron Asymmetric Ring (SPEAR)

This information is provided in response to Question C-3.2.6.

(viii) SLAC Positron-Electron Project (PEP)

This information is provided in response to Question C-3.3.6.

(ix) SLAC Linear Collider (SLC)

This information is provided in response to Question C-3.4.4.

2. **How much funding has been provided by other agencies such as the National Science Foundation for each of the facilities enumerated in question 1 above?**

Answer: The following indicates the funding which was provided or is planned to be provided by other agencies to the high energy physics laboratories:

DOE Laboratory	Source	Estimate FY 1981 - FY 1985
Brookhaven Nat'l (AGS)	National Sci. Foundation	$ 114,000
Fermi Nat'l Accel.	National Sci. Foundation	60,000
Stanford Linear Accel. Center (SPEAR)	National Sci. Foundation	3,222,000
Fermi Nat'l Accel	Nat'l Aeronautics and Space Administration	300,000

In addition to the above, many of the users who perform experiments at the DOE facilities receive their direct research support through grants from the National Science Foundation.

3. **What is the High Energy Physics program's user policy for each of the facilities listed in question 1 above?**

Answer: The program's user policy, which applies to all of the Department's high energy physics facilities, is to make these facilities available to qualified users on the basis of the scientific merit of their proposals. The program relies on the laboratory management to establish an appropriate mechanism to review proposals from prospective users and to make decisions regarding disposition of proposals and scheduling of approved experiments. The DOE program office is available to hear appeals in case of disputes which cannot be resolved at the laboratory level. The policies and procedures adopted by the laboratories, though differing in details, all have the same general features.

The first level of scientific review of experimental proposals is the Laboratory Program Advisory Committee (PAC). The PAC whose membership includes outstanding physicists from the university community, the host laboratory, and other laboratories, reviews proposals on the basis of scientific merit, competence of participants, and effectiveness of the proposed plan and resources of the proposer and laboratory to accomplish the job. DOE staff participates in PAC meetings as observers. The committee makes recommendations to the laboratory management which makes the final decision to accept, reject or defer a proposal, and, if accepted, to schedule the experiment for beam time. For approved high energy physics experiments, the laboratory will provide beam time free of charge and some supporting services and apparatus as appropriate. In addition to providing beams, targets, experimental areas and a pool of common electronic components, the laboratory also provides services such as computing, rigging, office space and laboratory space during the course of the experiment.

To receive funding for direct research costs such as salaries, travel, publication expenses, etc., a research group must submit a funding proposal to the DOE or NSF. This proposal will undergo an extensive review process by the Department, generally including peer review. The DOE review process considers the overall scientific merits of the proposal, the performance record and potential of the proposers, funding considerations and the resources and support to be provided by the sponsoring institutions.

4. **For the period FY 1981 - FY 1985, by facility and by user, how much reimbursable research has taken place and is expected to take place? What revenues have been involved?**

Answer: The following tabulates the reimbursable research that has taken place:

DOE Laboratory	Source	Use	Estimated Funding FY 1981 - 1985
Fermilab	National Cancer Institute	Neutron Therapy Facility	~ $ 5,000,000
BNL	Biological and Environmental Research Program	BNL Linac Isotope Production Facility	$ 680,000
SLAC	National Science Foundation	SSRL	$ 3,222,000

The reimbursed costs are incremental costs associated with providing beam for these non high energy physics purposes.

1.0 Brookhaven National Laboratory (BNL)

1.1 Alternating Gradient Synchrotron (AGS)

1. **What new science is being explored by this facility? What scientific opportunities are being exploited?**

Answer: The most important new opportunity being exploited at the Alternating Gradient Synchrotron (AGS) is the search for rare kaon decays. Under the presently accepted standard model such decays are either totally excluded or suppressed to the order of one decay in 10^{12} (one million million). We know, however, that the standard model is not complete. New science beyond the standard model must exist and some examples of such new science would predict these kaon decays at higher rates. If these were observed, it would be a major breakthrough, comparable for example to discovery of nucleon decay, and would reveal structure otherwise only observable by a super accelerator [such as the Superconducting Super Collider (SSC)]. Three rare decay mode experiments are currently approved. There is a letter of intent for a fourth, and preliminary discussions on at least one more. These experiments have been given overall highest priority at the AGS. In the world, there is no source of kaons with comparable intensity.

Another important opportunity being exploited is that provided by the high quality neutrino beam. A currently running experiment is providing the most accurate determination of the Weinberg angle, one of the most fundamental constants in the standard model and one which, when sufficiently well measured, provides a critical constraint on the new science beyond the standard model. Another approved experiment will provide one of the most sensitive tests of neutrino oscillations. Such oscillations would be expected if the neutrino had a small but finite mass. This again is something which is expected beyond the standard model and is, thus, critical to our understanding of the fundamental nature of particles. The neutrino beam at Brookhaven is the most intense in its energy range and, thus, unique limits will be set by these experiments.

The polarized proton capability at the AGS is just being commissioned and is by far the highest energy polarized proton source in the world. Experiments are being prepared to exploit this beam. Many other areas of physics are being explored using the unique high intensity beams, including studies of quantum chromodynamics, dibaryons, exotic atoms, and hypernuclei.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

Answer: The Alternating Gradient Synchrotron (AGS) presently operates with a maximum proton energy of 28 GeV and a primary beam intensity of up to 1.4 x 10^{13} protons per second. The primary proton beam is used to make a variety of secondary beams. Work is under way to add to the AGS the capability to accelerate high energy polarized protons (to be operational for research by the beginning of FY 1985) and high energy heavy ions (to be operational by late FY 1986). The CERN Proton Synchrotron (PS) in Geneva, Switzerland is similar in its intrinsic capabilities, except for the polarized proton and heavy ion capabilities. However, the PS is no longer being used for physics research but is fully dedicated to serving as an injector for other machines on the CERN site. The KEK proton synchrotron in Japan has a maximum energy of only 12 GeV and factor of five lower beam intensity. Brookhaven National Laboratory (BNL) is developing plans for a series of upgrades to the AGS which would increase the beam intensity to 10^{14} protons per second and substantially improve the operational effectiveness. This overall plan has been called AGS II. Los Alamos National Laboratory has under consideration a plan to propose a major addition to the Los Alamos Meson Physics Facility (LAMPF) called LAMPF II. LAMPF II, as presently discussed, would have a peak energy in the range of 15-30 GeV and a beam intensity of perhaps 5×10^{14} protons per second.

3. **What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?**

   Answer: The Multi-Particle Spectrometer (MPS) is a large electronic detector and spectrometer facility maintained by Brookhaven National Laboratory (BNL) and available to the user community. It is a very high rate tracking and particle identifier and is the only detector facility so maintained at the AGS. There is a significant inventory of large spectrometer magnets, specialized electronic equipment, Cerenkov counters, beam diagnostic monitors, etc., available for use in experimental set ups. In addition, the On-Line Data Facility provides a real time data handling capability for experimental data acquisition and analysis via a system including a DEC KA10, KL10, and VAX 11/780. Spectrometers built and maintained by Alternating Gradient Synchrotron (AGS) user groups are also available to others through collaborative arrangements. These devices range from table top Ge-Li detectors to two neutrino detectors of 175 tons and 300 tons, respectively.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

   Answer: Many of the most important experiments carried out, and to be carried out (e.g., the rare kaon decay mode searches) at the Alternating Gradient Synchrotron (AGS), involve the search for new "exotic" reactions or states. Such reactions are not "allowed" by accepted theories and models, and, if observed, would become sensitive probes of the deeper physics beyond that simpler picture. Not surprisingly, most such searches do not find specific exotic reactions but, rather, set constraints on what that new physics can be. In other cases, something is seen which then requires an explanation from the theorists. Experiment 747 (a Brookhaven National Laboratory/City College of New York collaboration) at the AGS is a good example of finding something unexpected. The experimenters looked for a particular reaction that is not allowed by an old theoretical rule (the OZI rule) if the new state is like other mesons, i.e., made of a quark and antiquark pair. Surprisingly, the experimenters found two, and probably three, new states. Their discovery means either that the OZI rule is violated or that these states are something new, such as "glueballs" (bound states of gluons with no quarks). If so, they may well turn out to be the first identified "glueball" states. This experiment is continuing and, as always, independent confirmation will be required.

   An example of the type of experiment that did not find an effect, but rather set a better limit on possible deviations from the theory, is Experiment 735 (a Yale/Brookhaven National Laboratory collaboration) which did a sensitive search for violations of time reversal invariance. Such violations are predicted by theories which give elegant explanations of the violations of CP invariance (which was discovered at the AGS and was the basis of the 1980 Nobel Prize in Physics). In $K \to \pi\mu\nu$ decay, the component of the μ spin perpendicular to the decay plane changes sign under time reversal. Thus, time reversal invariance requires that the μ spin cannot have a component in this direction. The experiment measured the direction of the μ spin. After observing over thirty million K decays, they found that the spin component in the forbidden direction is $P_n = 0.0024 \pm 0.0041$. The muon spin direction is, thus, found to be entirely in the allowed plane as required by time reversal invariance.

A somewhat different kind of experiment involves looking for something which is predicted by a theory, but has never been observed. Experiment 722 (run by a BNL group) is an example of this kind of search. It is looking for a predicted meson state, that would be made of two quarks and two antiquarks (all known mesons are made of only one of each). The state (H) would be made in the reaction $pp \to K^+K^+H$ and is being searched for in this experiment by identifying and measuring the two K^+'s and, thus, inferring the existence of the H. Nothing has been seen so far, but the analysis is not complete. Final results will be reported by FY 1985.

An example of an experiment whose objective is to measure a particular basic parameter (the Weinberg mixing angle θ_W) of an established theory (the Weinberg-Salam electroweak theory) is Experiment 734, a Brookhaven National Laboratory/Brown University/KEK/Osaka/University of Pennsylvania/State University of New York collaboration. It has such discovery potential since theories beyond the standard model would predict that what seam like measurements of this parameter made in different ways could give different answers, thus, revealing the presence of "new physics."

The AGS experiment, which is being done in a neutrino/antineutrino beam, compares the rates for the reactions $\nu_\mu e \to \nu_\mu e$ and $\bar{\nu}_\mu e + \bar{\nu}_\mu e$ (the current experiment will observe 167 νe and 90 $\bar{\nu} e$ events and will represent the world's largest and also cleanest sample). Some results have already been published. The determination of the Weinberg angle (θ_W) will be published shortly and is expected to have the world's smallest error in this measurement. An extension of the experiment has recently been approved.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer:

FY 1981

1. D split in the beam switchyard completed and tested.

   -- Provides for a fourth simultaneously operating primary proton beam and thereby allows increased experimental multiplicity.

2. C1/C3 beam split completed and tested.

   -- Allows for simultaneous operation of C1 and C3 secondary beams, thereby increasing experimental multiplicity.

3. A3 beam (neutral kaons) built for CP violation experiment.

4. B4 beam (pions and kaons) built for H meson search experiment.

5. Completed construction of E734 neutrino experimental area.

6. Completed construction and commissioning of new fast extraction system which increases extraction efficiency and reduces beam loss during fast extracted beam running.

FY 1982

1. D Line primary proton target station completed and commissioned.

   -- Provides fourth target station and increases multiplicity of simultaneous experiments by 33 percent.

2. C1 beam built and commissioned for 90° inclusive scattering experiment.

3. B5 neutral beam built and commissioned for Ω^- experiment.

4. Multi-Particle Spectrometer (MPS) upgrade completed and commissioned.

   -- Provides factor of ten improvement in rate handling capabilities and factor of three better resolution.

5. C6, C8 beam upgrades completed

   -- Provides for the world's most intense low energy antiproton beams.

6. H^- charge exchange injection project completed.

   -- Provides for higher intensity internal proton beam and reduces induced radioactivity which leads to reduced radiation burden to personnel.

7. Siemens motor and generator rotors were removed and refurbished. This is the main power supply for the Alternating Gradient Synchrotron (AGS) ring.

   -- The AGS acceleration power supply had executed 2×10^8 pulses since 1970. A major overhaul was required for continued reliable service.

FY 1983

1. D2, D4 stopping muon beams completed and commissioned.

   -- Provides a unique single bunch muon beam for quantum electrodynamics vacuum polarization experiment.

2. Hypernuclear spectrometer upgrade completed.

   -- Provides for a forefront world facility for the study of hypernuclear systems.

3. B1 beam (multiparticle test beam) constructed and commissioned.

   -- Provides for a new test beam. Many user groups with experiments at Brookhaven National Laboratory and Fermilab have been using this beam.

4. Single bunch extraction mode operation was commissioned.

   -- Provides for simultaneous operation of the Fast Extracted Beam (for neutrino experiments) and a single proton bunch to E745, the QED experiment in the D2 beam.

FY 1984 (expected)

1. North area target station reconstruction completed.

   -- Provides for a new narrow band neutrino beam for neutrino oscillation experiment (E776).

2. Neutrino oscillation experiment (E776) construction completed.

3. D3 K^+ beam construction completed for flavor changing neutral current decay experiment (E777).

4. A3 K^0 beam construction completed for flavor changing neutral current decay experiment (E780).

5. Polarized proton acceleration project completed and commissioned.

   -- Provides a unique world facility of polarized protons up to 26 GeV/c

6. Siemens motor generator set controls automated. Provides for a reduction in shift personnel.

7. AGS intensity upgrade from 1.0 → 1.8 × 10^{13} protons/pulse completed.

   -- Achieved 1.6 × 10^{13} protons/pulse as of March 1, 1984.

8. Completed installation of internal gas jet target.

FY 1985 (expected)

1. C4 K^+ beam construction to be completed for flavor changing neutral current decay experiment (E787).

2. Construction of D5 time separated antiproton beam will begin.

3. Initiate further AGS intensity upgrade

    -- Provides for a factor of two increase in accelerated proton intensity to 3×10^{13} ppp. Allows for either simultaneous Slow Extracted Beam (SEB)/Fast Extracted Beam (FEB) operation or enhanced single mode SEB or FEB operation.

4. Begin AGS polarized proton intensity upgrade (Phase 1).

    -- Provides for an increase of a factor of 100 in polarized proton intensity with the construction of a new polarized H^- ion source.

5. Complete construction of a new wide band neutrino horn (E734).

6. B5 very high intensity K^0 beam constructed for the flavor changing neutral current decay experiment.

6. For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table presents the requested data.

(Budget Authority in Thousands)

Budget Profile	Source of Funds	FY 1981	FY 1982	FY 1983	FY 1984	Estimate FY 1985
AGS Operations	HEP	$22,450	$24,150	$33,300	$33,800	$37,800
In-House Research	HEP	5,620	5,690	5,880	6,500	7,060
Out-of-House Research*	HEP	350	400	530	500	440
Other Oper. Expenses	HEP	3,253	1,007	405	3,910	5,490
Capital Equipment	HEP	2,050	2,350	2,575	3,200	4,100
General Plt. Project	HEP	330	110	543	360	2,050
In-House Energy Management	In-House Eng. Mgmt.	348	676	103	968	500
Accel. Improvements	HEP	1,400	1,500	1,500	2,000	2,000
Total AGS		$35,837	$35,883	$44,836	$51,238	$59,440

* Out-of-House research effort by BNL staff is an estimate, accurate to about ± $100 K.

7. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

Answer: The only other source of direct funding to Brookhaven National Laboratory for the Alternating Gradient Synchrotron (AGS) is the National Science Foundation (NSF). The funding from NSF is as follows:

(Budget Authority in Thousands)

FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
$ 1	$ 26	$ 37	$ 35	$ 15

There is, of course, indirect support for the AGS related research program through university users, some of whom are supported by NSF grants.

8. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

Answer: The actual and estimated staffing levels are given below:

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Full time equivalents	449	414	462	481	471

9. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

Answer: The requested utilization data are given in the table which follows:

Weeks of Operating for Physics Research

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Total	24	23	29	32	35
Slow extracted beam mode	16	12	13	17	15
Fast extracted beam mode	8	11	16	10	10
Polarized Proton	--	--	--	5	10

Full utilization for the Alternating Gradient Synchrotron is estimated to be about 45 weeks per year.

10. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer: The requested data is presented in the following table:

AGS Experiments

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Started	5	9	10	9	12
Continued	4	3	9	11*	9*
Total	9	12	19	20	21
Completed	6	3	6	13	9

* Two experiments which ran in FY 1983 will not operate in FY 1984 but will be resumed in FY 1985.

11. What is this facility's user policy?

Answer: The laboratory policy is that any researcher whose proposal is judged to have sufficient scientific merit, after thorough review by the High Energy Physics Advisory Committee [recently renamed the Alternating Gradient Synchrotron (AGS) Program Committee] and laboratory management, may use AGS without charge for beam time and without regard to institutional affiliation or nationality provided the work is for pure research and the results are to be published. Industrial and/or classified use, where results will not be published, may take place, but such use is considered on a case-by-case basis and the user is expected to pay full operational costs.

12. For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?

Answer: There has been no reimbursable research within the high energy physics program at the Alternating Gradient Synchrotron (AGS), and we do not expect any. The Brookhaven Linac Isotope Production (BLIP) facility, operated by the DOE Biological and Enviromental Research (BER) program, is a parasitic user of the AGS facility. As such, the BLIP facility program funded by BER reimburses the AGS for incremental costs associated with BLIP operation. The total reimbursement to the high energy physics program over the FY 1981 - 1985 period was $680,000. The BLIP program recovers a portion of its costs by selling radioactive isotopes for biomedical and other research purposes.

13. What is the mechanism by which specific research proposals for experiments at the facility are considered?

Answer: A proposal describing in detail the experiment to be performed, the scientific objective and justification, the plan for accomplishing the experiment and the resources to be committed by the users is submitted to the Associate Director for High Energy Physics at the Laboratory. The technical aspects of the proposal are reviewed by the Experimental Planning Support Division (EPS). EPS also considers the Laboratory resources which will be required to install and support the proposed experiment, and the availability of the secondary beam and any other laboratory facilities being requested. At the same time, the proposal is submitted to the members of the Alternating Gradient Synchrotron (AGS) Program Committee (APC) (formerly the High Energy Advisory Committee). Following a public presentation of the proposal at a meeting of the APC and deliberations by the Committee, the APC makes a recommendation to the Associate Director for High Energy Physics at the laboratory, who makes the final decision. The decision is based on the Committee's recommendations and consideration of the scientific justification of proposed research, the technical feasibility of the planned approach, the qualifications of the proposing groups, and the impact on the Laboratory resources.

14. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

    Answer: From January 1979 through December 1983, 52 experimental proposals were submitted. Of these, 37 were approved.

15. **How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?**

    Answer: Approximately 450 researchers (both faculty and students) from about 75 educational institutions have participated in experimental work using the facilities at the Alternating Gradient Synchrotron (AGS) over the past five years. Approximately one fourth of these received their support from the National Science Foundation.

16. **How many industrial researchers have utilized the facility over the past five years?**

    Answer: Approximately five industrial researchers have used the Alternating Gradient Synchrotron facility during the past five years.

17. **How many researchers from foreign institutions have utilized the facility over the past five years?**

    Answer: Approximately 30 researchers from foreign institutions have used the Alternating Gradient Synchrotron facility over the past five years.

18. **How many researchers from other agencies have utilized the facility over the past five years?**

    Answer: Approximately 30-35 researchers who are employees of other Federal agencies (i.e., Naval Research Laboratory and National Oceanographic and Atmospheric Administration) have used the Alternating Gradient Synchrotron (AGS) facility in the past five years, primarily for irradiation of integrated circuits. In addition, in the same period, approximately 125 university-based researchers supported by the National Science Foundation have participated in AGS experiments.

19. **What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

    Answer: The Alternating Gradient Synchrotron (AGS) is presently capable of accelerating protons to 28 GeV with a peak intensity of 1.4 x 10^{13} protons per pulse. Work is well along to extend the capabilities of the AGS to include the acceleration of polarized protons and light ions. It is projected that polarized protons will be available for research by the beginning of FY 1985 and that light ions will be available later in FY 1986.

There are many potential future development possibilities for this accelerator facility, but there are currently no approved plans to undertake any of them beyond the activities identified in the FY 1985 budget request. New research instruments and experimental devices will be developed as the physics research program progresses. We intend to give high priority to the exploitation of the facility's unique capabilities.

20. What will be the Impact of the Nuclear Physics Tandem/AGS Heavy Ion Transfer Line project (Project No. 84-R-123) on the AGS high energy physics program?

Answer: The Heavy Ion Transfer Line project will have little impact on Alternating Gradient Synchrotron (AGS) operations during the construction phase. The connection to the AGS ring tunnel and installation of the AGS modifications will be done during normal shutdown periods. Commissioning of the AGS heavy ion beam capability, planned in FY 1986, should require four to six weeks of machine time.

Five weeks of dedicated operation for heavy ion research are planned for FY 1986. In subsequent years, ten weeks per year of heavy ion operation are projected. Within a total practical limit of 45 weeks per year for AGS operation, this would limit the high energy physics program to about 35 weeks per year, which is the same as the AGS operating level planned in FY 1985. An average of seven weeks per year is required for maintenance.

21. Please provide a copy of the facility's latest annual report.

Answer: The Alternating Gradient Synchrotron (AGS) facility does not prepare an annual report. On a biennial basis, the Laboratory prepares a summary report entitled Brookhaven Highlights. We have attached the high energy physics portion (pages 3-32) of the most recent Brookhaven Highlights. In addition, we have attached copies of several recent monthly status reports.

BNL 51700
UC-2 and 13
(General, Miscellaneous, and Progress Reports
(Nuclear and Nonnuclear) — TIC-4500)

BROOKHAVEN HIGHLIGHTS

January '82 — March '83

High Energy Physics
Physics and Chemistry
Life Sciences
Applied Energy Science
Support Activities
General and Administrative

Editors: J.B. Horner Kuper and Mary C. Rustad

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United States Department of Energy

High Energy Physics

High Energy Physics Research
Accelerator Department
CBA

Accelerator and High Energy Physics Programs

General Introduction

The frontier of knowledge which most occupies the elementary particle physicist is the world of the very small; as matter is broken down into more and more fundamental constituents, shorter and shorter distance scales are probed. By the uncertainty principle of quantum mechanics, such studies necessarily entail work with particles of high momenta or energies. Thus the synonymy between elementary particle and high energy physics appears.

The need for large and powerful accelerators to study elementary particles has resulted in large user groups performing experiments at such major national laboratories as Brookhaven, the Fermi National Accelerator Laboratory, and the Stanford Linear Accelerator Center. Indeed, the high energy physics program is the largest single item in the Brookhaven Laboratory budget.

At present, the high energy experimental program at Brookhaven centers around the Alternating Gradient Synchrotron (AGS), which accelerates protons to an energy of 30 billion electron volts (GeV). Beams of these protons, or secondary particles produced by them, are used as projectiles to explore subnuclear matter. By studying the way in which the projectile particles interact with target particles inside an atomic nucleus, much can be learned about the constituents of subnuclear matter and about the forces which govern their interactions. At present it appears that the neutrons and protons that make up atomic nuclei are themselves formed of more fundamental entities called quarks, which are bound together by gluons, special particles which transmit the strong force. Many other particles produced in high energy scattering experiments are also believed to be composed of various combinations of quarks held together by gluons. All together there are perhaps half a dozen varieties of quarks, and a similar number of leptons (an equally fundamental class of particles of which a familiar example is the electron). This modest number of quarks and leptons plus their antiparticles and a few force-carrying particles such as the gluon are thought to explain all of the rich variety of matter. This model of the physical world has had outstanding success, but many questions and puzzles remain. Not all the predicted particles have yet been observed and not all the observed ones are fully understood.

One of the puzzles relating to particle dynamics is the apparent impossibility of isolating a single quark. After a high energy collision, all quarks and antiquarks involved manage to cluster together into the known bound states. Much recent elementary particle physics research has sought to understand the nature of the interquark forces which give rise to this confinement phenomenon while leaving the quarks relatively weakly interacting when near each other.

It is the aim of the Brookhaven High Energy Physics program to investigate these most fundamental questions while providing a center where scientists from other institutions can use the most powerful research tools available for this purpose.

Proposals for experiments using the AGS must be submitted to the High Energy Advisory Committee which is composed of highly qualified physicists representative of the entire user community. This committee advises the Deputy Director for High Energy Physics, who must approve all experiments scheduled on the AGS. About 80% of the research is carried out by visiting scientists from universities, from other national laboratories, and occasionally from abroad.

The Accelerator Department operates the AGS and its experimental areas, providing the beams of protons, antiprotons, kaons, pions, and neutrinos needed for experiments. Department personnel assist the experimenters in setting up their apparatus and provide many services essential to carrying out experiments. Large facilities, such as the Multiparticle Spectrometer and the On-Line Data Facility, are constructed, operated, and maintained by the Department. Some of the Department physicists also participate in research.

The Physics Department is staffed with both experimentalists and theorists. The experimentalists are mainly engaged in research at the AGS, but a fraction of their work is carried out at other accelerators. The theorists provide the stimulus of exciting new ideas in particle physics and devote much of their time to a study of results from experiments using the AGS and other high energy accelerators in the U.S. and Europe.

The High Energy Discussion Group (HEDG) is an organization brought into being by the community of university and national laboratory users of AGS "to provide an organized channel for the interchange of information between those who utilize BNL high energy facilities for their research and the Laboratory administration." HEDG holds one general meeting at BNL every spring. Much of the work of the users group is coordinated by the HEDG Executive Committee which meets three times a year.

High Energy Physics Research

INTRODUCTION

High Energy Physics is the major research activity at Brookhaven National Laboratory. Most of the experimental research is carried out at the Alternating Gradient Synchrotron (AGS) by members of the Physics Department (listed on p. 56) and the Accelerator Department in collaboration with many university groups. The AGS accelerates protons up to energies of 30 GeV. The primary proton beam can be used directly or to produce secondary beams of other particles, such as neutrinos, mesons, antiprotons, etc. These particle beams are the main resources for experimentalists who have used them to perform six to ten experiments each year for the last 22 years. Some of these experiments led to discoveries that had a profound impact in this field. Over the last eight years (since the discovery of the J/ψ particle at the AGS and SLAC), a consensus has emerged on a standard model for describing the fundamental interactions of nature: quantum chromodynamics (QCD) for the strong interactions and the Weinberg-Salam theory to describe the weak and electromagnetic forces as manifestations of a unified field theory.

Despite its venerable age, the AGS continues to support a very vigorous and diversified program; experiments being carried out now or in the next few years still have the potential of altering the standard model in a significant way. The AGS provides the most intense ν_μ, $\bar{\nu}_\mu$ (muon neutrino, antineutrino) beams available anywhere in the energy range 1 to 10 GeV, which are ideally suited for the study of the $\nu_\mu(\bar{\nu}_\mu)$e and $\nu_\mu(\bar{\nu}_\mu)$p elastic scattering and for the search for neutrino oscillations — the change of ν_μ into another type of neutrino such as ν_e (electron neutrino) or ν_τ (τ neutrino). The observation of oscillations would imply that neutrinos have mass, an observation with profound implications for cosmology, since in that case most of the mass of the universe would be in the form of neutrinos. The study of $\nu_\mu e^-$ and $\bar{\nu}_\mu e^-$ scattering is a very sensitive check of the Weinberg-Salam unified theory.

The most intense K-meson beams are provided by the AGS in the same energy range. These beams are used for the study of rare K-meson decays, a low energy probe of the structure of interactions at much higher energies. The phenomenon of charge-parity (CP) violation, or, equivalently, time-reversal (T) violation (discovered in K^0 decays at the AGS in 1964), which implies that matter and antimatter are not symmetric, is still poorly understood. The only way physicists have found to study it is with K decays. Also, sensitive searches of K decays forbidden by the standard model are very powerful tests of the model; observations of such decays would necessarily lead to modifications or expansions of the model in a very fundamental way.

Intense beams of π, K, and $\bar{p}$ particles are also used to study hadron spectroscopy, a field to which experiments at the AGS have made significant contributions in the past (among them the discovery of the Ω^- and Λ_c^+ baryons and the J/ψ meson). The standard model explains practically all observed hadrons as made of a quark and antiquark ($q\bar{q}$ mesons) or three quarks (qqq baryons). It also requires the existence of glueballs (states with no quarks) and does not forbid the possibility of more complex states such as six quarks (dibaryons) or two quarks and two antiquarks ($qq\bar{q}\bar{q}$ mesons). The existence of glueballs is fundamentally related by QCD to the permanent confinement of quarks inside hadrons; in other words, the fact that no free quarks are observed in nature implies the existence of massive states with no quarks. It is difficult to distinguish glueballs from neutral $q\bar{q}$ states, and only detailed studies of hadronic states and their decay properties can eventually show whether glueballs are required to explain the observed spectrum.

In addition to experiments at the AGS, members of the Physics Department also collaborate on experiments at FNAL and CERN. In the former, photographs of neutrino interactions in the FNAL 15-ft bubble chamber are scanned and measured using the facilities for bubble chamber film existing at BNL. The main objective of these experiments has been to study $\nu_\mu e^-$ scattering and charm-particle production. At the ISR at CERN a number of physicists from the Physics Department are part of the Axial Field Spectrometer collaboration (R807), one of the largest and most ambitious experiments ever mounted at that facility. The highest center-of-mass energy at the ISR is ideally suited for the study of quark-quark scattering, a very basic process in QCD.

Not all high energy experiments require the use of accelerators or colliding beams; in fact, a test of our understanding of physics at energies beyond those accessible by any conceivable accelerator involves the search for proton decay. Attempts to unify the strong interactions with electroweak interactions (grand unified theories, or GUTs) predict that the lifetime of protons is finite, albeit very long compared to the age of the universe (since its formation, less than 10 kg of the earth may have decayed). In a collaborative search for such improbable events, physicists from BNL, the University of Michigan, and the University of California at Irvine have built a large tank containing 8000 tons of water inside an Ohio salt mine 600 m underground. This is the largest facility of its kind and the only one at present sufficiently massive to rule out the simplest grand unified theory if no proton decay is observed.

The Physics Department is also home to a very active high energy physics theory group that helps formulate or investigate the consequences of existing models of the fundamental interactions. Grand unified theories have been studied in an effort to refine predictions of proton decay, numerical calculations with lattice gauge theories (a method pioneered at BNL) have been done to predict glueball masses, and a Monte Carlo program has been developed to describe as realistically as possible the types of events to be expected in present and future hadron colliders; these are but a partial list of the contributions of the theory group.

In addition to the above endeavors, many experimentalists and theorists have been working together over the past year generating ideas

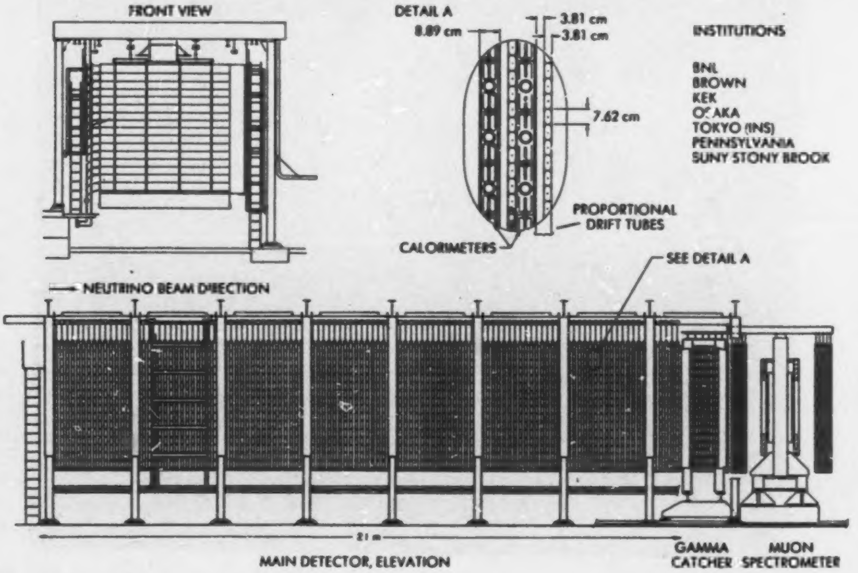
FRONT VIEW
DETAIL A
8.89 cm
3.81 cm
3.81 cm
7.62 cm
INSTITUTIONS
BNL
BROWN
KEK
OSAKA
TOKYO (INS)
PENNSYLVANIA
SUNY STONY BROOK
PROPORTIONAL DRIFT TUBES
CALORIMETERS
SEE DETAIL A
NEUTRINO BEAM DIRECTION
21 m
MAIN DETECTOR, ELEVATION
GAMMA CATCHER
MUON SPECTROMETER

Figure 1. a) The BNL neutrino detector: 100 tons of liquid scintillator calorimeter and proportional drift tubes.

for experiments at the planned Colliding Beam Accelerator (CBA).

The most interesting results of the research carried out during the past year are discussed in the following sections.

NEUTRINO EXPERIMENTS

Experiments with neutrino beams have been among the main staples of the AGS since it began operation; the first experiment at BNL in 1962 demonstrated that the muon neutrino, ν_μ, is different from the electron neutrino, ν_e. As neutrinos have very small cross sections, a great deal of effort has gone into making the beams as intense as possible and the experiments as massive as can be afforded.

For many years one of the major facilities for neutrino experiments was the BNL 7-ft bubble chamber which was decommissioned in 1980. Data from that chamber are still being analyzed in collaboration with Tohoku University, Japan. A new 100-ton detector has now been operating for almost two years. It consists of 118 modules of scintillator and proportional drift tubes which form both the target material and the detector for the secondary products of a neutrino interaction. The detector needs to be this massive, as one of its major goals is to measure $\nu_\mu e - \nu_\mu e$ scattering. This is one of the cleanest reactions for testing the Weinberg-Salam theory, but it has an extremely small cross section: 10^{-42} cm^2, 16 orders of magnitude below that of strong interactions. The detector is shown schematically in Fig. 1a. In an international collaboration (E734), a group of Japanese and American physicists (BNL-Brown-KEK-Osaka-Stony Brook-Tokyo) has been taking data and getting one neutrino interaction per AGS pulse on the average. The detector is optimized for the de-

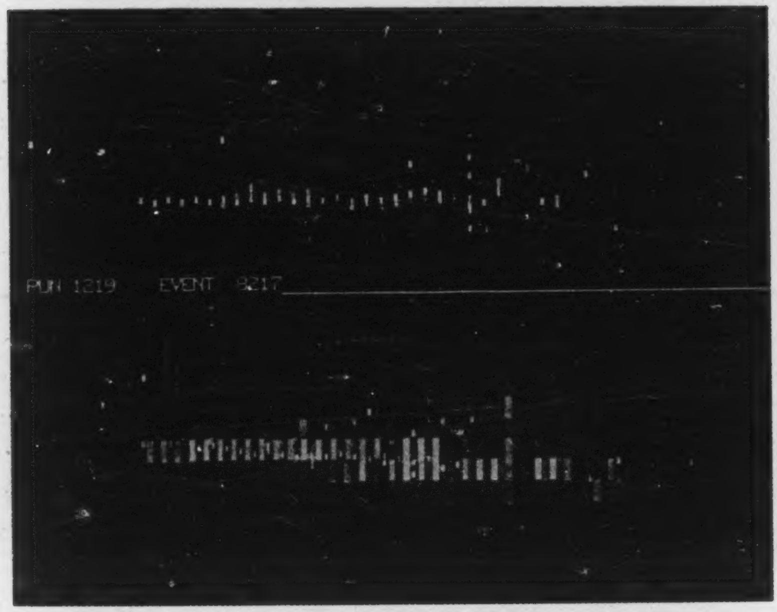

Figure 1. b) A $\nu_\mu e^- \rightarrow \nu_\mu e^-$ event in the detector. The color in each cell gives the amount of energy deposited, dark blue is the lowest detectable (<0.5 minimum ionizing) and red the highest grade (>4.5 minimum ionizing).

tection of the elastic scattering reactions $\nu_\mu e^- \rightarrow \nu_\mu e^-$ and $\nu_\mu p \rightarrow \nu_\mu p$. The first reaction is characterized by a single outgoing electron in the forward direction. Figure 1b shows what such an event looks like in the detector, a very characteristic electromagnetic shower in the forward direction. The color of each cell in the picture is related to the energy deposition, and it is straightforward to observe the fluctuations in energy typical of electromagnetic showers. Such showers can also be produced by high energy photons, but the beginning of the shower would show twice as much energy since a photon converts to an electron-positron pair. The event separation from the photon background is very clean, as can be seen in Fig. 2. The peak at the origin is due to the $\nu_\mu e^-$ reaction; the events at wider angles are from background processes. The signal-to-background ratio of 5 to 1 is about 5 to 10 times better than that achieved in higher energy experiments elsewhere.

The same apparatus has been used in a five-week run (E775) to search for $\nu_\mu \rightarrow \nu_e$ oscillations using the existing BNL narrow-band beam. This short experiment is a test run for a more ambitious program to search for ν_μ oscillations with a more intense lower energy narrow-band beam ($E_\nu \approx 1$ GeV) being built now. Even with this short run it is expected that E775 will be more sensitive to mixing angles than previous experiments. The signal for $\nu_\mu \rightarrow \nu_e$ oscillations would be the observation of electrons with the same energy as μ^- produced by ν_μ. It is also possible to look for $\nu_\mu \rightarrow \nu_\tau$ oscillations; the signal would be an apparent attenuation of the ν_μ beam as it goes through the detector. A more sensitive method is to use two detectors some distance apart, and there are plans to do this in a future experiment.

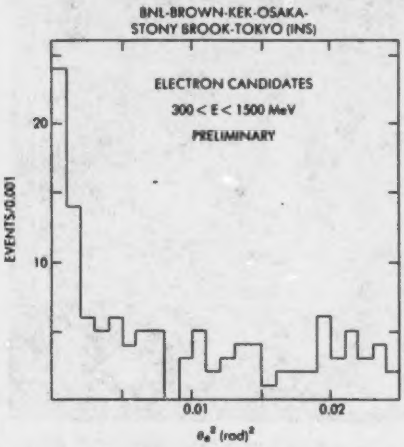

Figure 2. Angular deviation of electron candidate events from incoming neutrino beam direction. The peak near $\theta_e^2 = 0$ is due to $\nu_\mu e^- \rightarrow \nu_\mu e^-$ events.

The scanning and measuring facilities for bubble chamber film are still being used for neutrino experiments in the FNAL 15-ft bubble chamber. The emphasis of those experiments has been on $\nu_\mu e^- \rightarrow \nu_\mu e^-$ scattering, charm production, and dilepton production. Among the most interesting observations from those experiments is that, while events into opposite-sign dileptons ($\mu^- e^+$) have the characteristics expected from charm production, the equal-sign dileptons (about 11 $\mu^- e^-$ events) cannot be explained by associated charm production; the number of events is too large and no strange particles seem to be produced with them. The mechanism responsible for these events is not understood at present.

WEAK DECAYS

So far the only examples of a violation of time-reversal invariance (T) are K^0 decays. In Exp. 735, a Yale-BNL collaborating group has looked for a violation of T in the decay $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu$. If this decay is T invariant the spin of the μ^+ must lie in the plane of the decay, so the experiment searched for a component of the μ^+ polarization perpendicular to the decay plane. This was accomplished by stopping the μ^+ in an aluminum polarimeter and observing its decay to an $e^+ + \nu_e + \bar{\nu}_\mu$. The e^+ goes predominantly in the direction of the spin of the μ^+. After sampling 33 million such decays (the world sample of such decays before this experiment was two million), the μ^+ polarization in the forbidden direction was found to be 0.0018 ± 0.0036, consistent with zero. This limit places strict constraints on theories which attempt to explain T violation by the exchange of Higgs scalars; depending on what order exchange gives rise to T violation, these theories are of two classes: milliweak or superweak.

The same group is ready to take data in an experiment (E749) designed to measure any difference in the ratio of charged-to-neutral two-pion decays for K-short and K-long meson decays. One unique feature of this experiment is that both K_s^0 and K_L^0 decays (and both decay modes) are measured in the same apparatus so that systematic differences in efficiencies are eliminated. Superweak T-violation models predict no measurable difference in this ratio, unlike milliweak models. The sensitivity of the experiment is expected to be sufficiently high to observe for the first time effects predicted by milliweak theories.

In another high-sensitivity experiment (E777), BNL is collaborating with the University of Washington and Yale University in getting ready to search for the rare decay mode $K^+ \rightarrow \pi^+\mu^+e^-$. This mode is forbidden by the standard model as it violates lepton number conservation. However, it is possible in extended technicolor models. An attempt will be made to measure this branching ratio with a sensitivity better than 10^{-12}, about two orders of magnitude below the present limit.

The first results from the Irvine/Michigan/BNL (IMB) proton lifetime experiment have been reported. The IMB detector is a chamber surrounded by 2000 photomultipliers and filled with 8000 tons of water (10^{33} protons). It is located 600 m underground in an Ohio salt mine to shield it from cosmic rays. An example of what an event looks like in that detector is shown in Fig. 3. The signal for a proton decay is

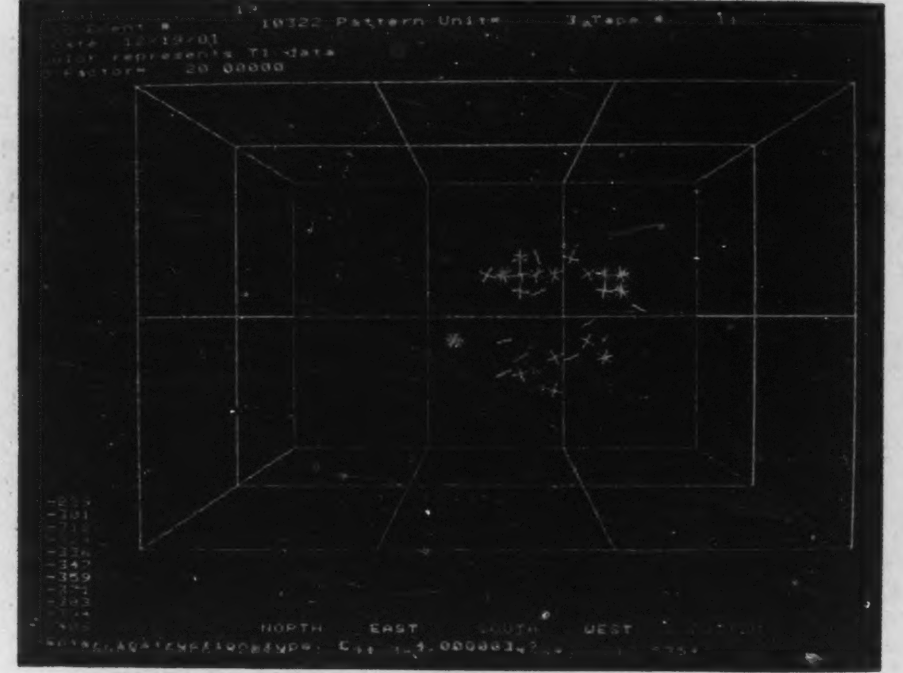

Figure 3. Computer graphics of Cherenkov light produced by a stopping muon, as seen in its direction of motion. One can see the ring of light. The number of crossing lines at each phototube is proportional to the amount of light seen by the phototube. The color indicates time of arrival of the signals at the phototubes, red is earliest time and blue latest.

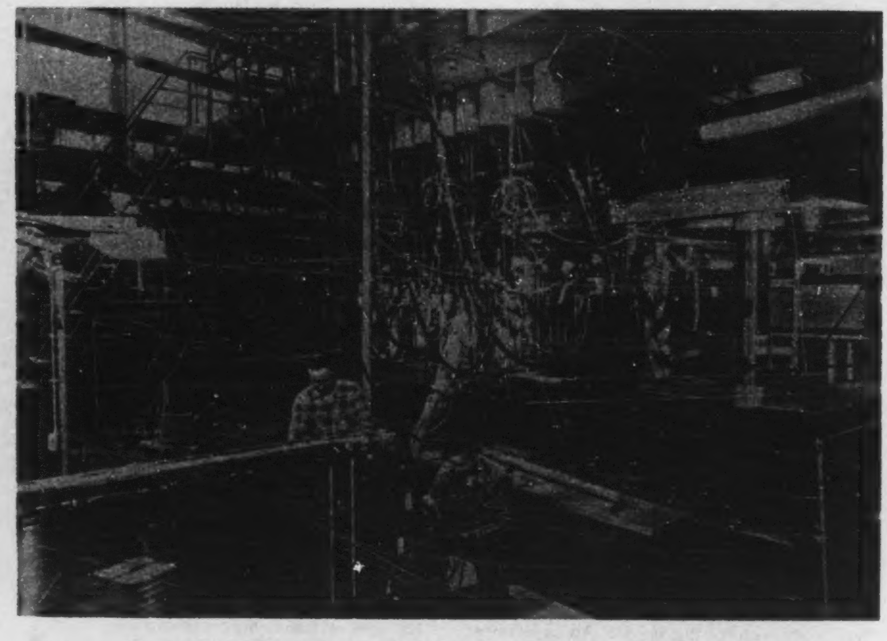

Figure 4. The MPS magnet and a drift chamber module being readied for insertion.

the Cherenkov light produced by relativistic electrons. In 80 days of continuous data taking no examples of the decay $p \rightarrow e^+\pi^0$ have been found, corresponding to a lower limit of 6.5 $\times 10^{31}$ years as the partial lifetime to this decay mode. The minimal SU(5) model (the simplest GUT model proposed) predicts a lifetime of 2 $\times 10^{29\pm1.7}$ years for the proton and $e^+\pi^0$ as its largest decay mode (~45%). The present limit is sufficiently stringent to rule out that model. Further data taking should push this limit beyond 10^{32} years and eventually (in two to three years) approach the ultimate limit of 10^{33} years. This upper limit is dictated by the background from cosmic neutrino interactions. Other GUT models becoming popular these days are supersymmetric theories, so called because they combine fermions and bosons into superfamilies. Their popularity is not due to any positive evidence but to their potential (not yet fulfilled) of unifying gravity with the other interactions. Supersymmetric models predict that the largest proton decay modes will be of type $K\mu$ or $K\nu$. These modes are much more difficult to detect, but it is expected that the IMB experiment will be able either to observe them or to put stringent limits on them.

STRONG INTERACTIONS

During 1982, all the spark chambers in the Multiparticle Spectrometer were replaced by a high-data-rate high-resolution drift chamber system. This new system (MPS II), shown in Fig. 4, was quickly brought into operation and 1200 events of the reaction $\pi^- p \rightarrow \phi\phi n$ were accumulated in a three-week run (E747) with a 22-GeV/c π^- beam; this is eight times more than were accumulated during a longer run with MPS I. From the data in MPS I, it was clear that this may be an interesting channel, as the production cross section was surprisingly large. A partial-wave analysis of the new data shows that it could be described by two interfering resonances with quantum numbers $I = 0$, $J^{PC} = 2^{++}$, one with mass 2160 ± 5 MeV and width 310 ± 70 MeV and the other with mass 2320 ± 40 MeV and width 220 ± 70 MeV. Although the cross section for the reaction is small (~20 nb), it is much too large to be easily explained by ordinary $q\bar{q}$ states decaying to $\phi\phi$, as such a decay mode is expected to be strongly suppressed for $q\bar{q}$ states produced by π^- beams. The most likely explanation in the context of QCD is that one or both of those states are glueballs or they are strongly mixed with glueball states. For glueballs the decay to a channel like $\phi\phi$ is as likely as any other (if they are sufficiently massive). At present, more data are being taken and the number of events is expected to increase by a factor of 4 to 5, which should make it possible to tighten the errors and look for additional states.

Three more experiments are scheduled to take data on the MPS II during the coming year, two concerned with glueballs and another studying radiative decays of hyperons.

While MPS II is now operating smoothly, data from the old MPS I are still being analyzed, with interesting results. An experiment studying the reaction $\pi^- p \rightarrow K_s K_s n$ (E705) with high statistics has produced evidence for two $I = 0$, $J^{PC} = 0^{++}$ states, one at $M = 1240 \pm 30$ MeV and width $\Gamma = 140 \pm 30$ MeV, referred to as g_s (1240), and another at $M = 1770$ MeV, called the S^{*1} (1770). This makes more 0^{++} states in that energy region than can be accommodated by a $q\bar{q}$ nonet, as the g_s (1240) does not seem to be the same state as the ϵ (1300) observed to decay to $\pi\pi$. The most natural way to explain the observed 0^{++} states is to assume that a $q\bar{q}$ nonet is strongly mixed with a glueball state to produce ten observable states.

In addition to $q\bar{q}$ (ordinary meson), qqq (baryons), and glueballs, QCD also allows the possibility of more complex states such as $qq\bar{q}\bar{q}$ and six quark states (so-called exotics), although what the characteristics of such states will be is not well understood. It could be that they exist for too fleeting a moment to be ever detected. It is generally acknowledged that above baryon-antibaryon thresholds the $qq\bar{q}\bar{q}$ states will preferentially decay to final states containing a baryon-antibaryon pair. Two MPS I experiments (E682 and E673) looked for these states in reactions expected to produce them, such as $\pi^- p \rightarrow \bar{p}p\pi^+$ + anything or $p\bar{\Lambda}\pi^+$ + anything (a $qq\bar{q}\bar{q}$ exchange process) or $\bar{p}p \rightarrow \bar{p}p\pi^0$(a baryon exchange process). Both experiments put very low limits (~10 nb) on the cross sections for producing $qq\bar{q}\bar{q}$ states with relatively narrow width (≤30 MeV) and masses in the range 1.9 to 2.5 GeV. If $qq\bar{q}\bar{q}$ states have widths comparable to those of the $q\bar{q}$ states, they would also have been observed if their cross sections are at the 100-nb level. From these experiments one can conclude that if $qq\bar{q}\bar{q}$ states exist at all they will be extremely difficult to observe.

Predictions concerning resonant states with QCD are difficult to make, although a method which seems to offer promise is the Bag model developed at MIT. Among its most striking predictions is the existence of a six-quark state (H) which would decay to $\Lambda\Lambda$ except that it lies below threshold and thus is expected to decay only weakly. This state has been searched for at the AGS in the reaction $pp \rightarrow K^+K^+ + H$ without success so far. In a previous experiment the limit on the production cross section was set at 30 nb. Data are now being taken in a new experiment (E722), which is expected to find the H if its cross section is bigger than 1 nb.

Another set of experiments at the AGS is concerned with the dynamics of quark scattering inside hadrons. Experiment 755, which ran for two weeks in June 1982 and is expected to take most of its data by next summer, studies only two-body final states from $\pi^- p$ interactions at 90° in the center-of-mass system. These processes are powerful tools for testing quark scattering models, but their cross sections drop so quickly with energy that these studies are not feasible at energies much higher than those available at the AGS. In another experiment concerned with dynamics, E748, proton-proton elastic scattering is being studied with a polarized target. This experiment is really a preparation for future experiments when the polarized proton beams become available at the AGS. At 90° in the center-of-mass system, very large spin effects were observed at the Argonne National Laboratory Accelerator ZGS before it was closed down. This phenomenon is not now understood and experiments with the polarized proton beam would show whether it persists at higher energies.

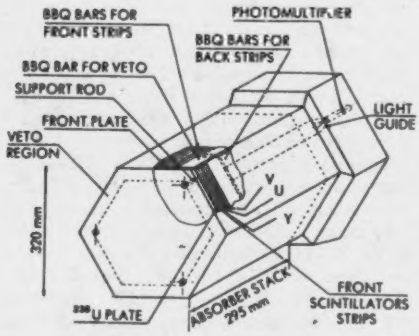

Figure 5. Small-angle electromagnetic calorimeter for the Axial Field Spectrometer at the ISR.

Physicists from BNL have also been very active in experiments at the CERN ISR, a good training ground for future experiments at CBA. The Axial Field Spectrometer Collaboration (R807) is the most ambitious experiment, in complexity and cost, ever mounted at the ISR. Among its novel instruments are hadronic and electromagnetic calorimeters built with scintillator and ^{238}U plates (provided by the U.S. government). At BNL a small special-purpose electromagnetic calorimeter with ^{238}U plates was built specifically to look for single γ, π^0, and η production at small angles (Fig. 5). The main motivation was the discovery of significant single γ production at 90° by a previous experiment (R806), also involving large BNL participation. This important discovery was the first indication of Compton scattering of quarks and gluons and bremsstrahlung by quarks. These processes should also produce single γ's at smaller angles, and various models based on QCD make different predictions on the expected cross section. The results from new measurements at $\theta = 11^\circ$ show substantial single γ production although much less than that expected by models predicting large contributions from bremsstrahlung of quarks at small angles. Another important result from R807 last year has been the first clear demonstration of the existence of jets at the ISR and, in particular, a demonstration of how jets become more and more apparent as the center-of-mass energy increases.

PARTICLE THEORY

The theory group's work has a very wide range, from numerical lattice calculations to fundamental interactions including grand unification schemes. Considerable effort has gone into studying the relevance of these ideas to future high energy machines.

Numerical computations with lattice gauge theories have been done to estimate the masses of pure gauge states (glueballs) as well as the spectrum of $q\bar{q}$ states. Among the important results of these computations are a demonstration of the recovery of rotational invariance in the continuum limit and a reduction of large N lattice gauge theory (the twisted Eguchi model).

In addition to lattice studies, continuum non-Abelian gauge fields were investigated, and connections to other nonlinear systems, such as soliton equations and general relativity, have been found. Solutions of the Dirac particle in the presence of a Bogolmonie-Prasad-Sommerfeld monopole have been found. These promise to clarify the possibility of proton-decay catalysis by monopoles.

In the Weinberg-Salam electroweak theory, radiative corrections were analyzed and the complete $O(\alpha)$ corrections to atomic parity violation and $\nu_\mu e$ scattering were computed. These calculations are important for interpreting the present neutrino experiment.

In the studies of GUTs, predictions of the supersymmetric SU(5) model were refined; in particular, the effects of intermediate-mass Higgs scalars on the predictions for $\sin^2\theta_W$ (Weinberg angle) and the proton lifetime. It was demonstrated that supersymmetric theories do allow an observable lifetime consistent with the present observed value of $\sin^2\theta_W$. It was also shown that the spontaneous breakdown of global baryon-lepton symmetry leads to possibly detectable neutron-antineutron and hydrogen-antihydrogen oscillations, with time scales related to the neutrino mass.

The phenomenology of quark mixing angles and CP violations in weak interactions has been studied in great detail, as has the production and decay properties of Higgs mesons, supersymmetric particles, and "bottom" and "top" particles, keeping in mind the new opportunities opened up by the CBA project. The Monte Carlo program ISAJET which simulates jet production in hadronic reactions has been used extensively to simulate the physics for CBA, including the production of supersymmetric hadrons, study of rare b-quark decays, and measurement of the $W^{\pm} + \gamma$ cross section. The program is also quite useful for analyzing many of the current experiments at CERN and FNAL.

PHYSICS AT CBA

During the past year working groups of theorists and experimentalists from the Physics Department, with some active participation from physicists in various universities, have been doing detailed studies on the feasibility of performing various experiments at CBA that exploit its unique features.

The physics potential of a pp collider at $\sqrt{s} = 800$ GeV was found to be extremely rich. Some of the important discoveries are expected to occur at the CERN $\bar{p}p$ collider ($\sqrt{s} = 540$ GeV), such as the $W^{\pm}$ and Z^0 bosons and the top quark (if its mass is below 70 GeV). However, many other fundamental measurements require the high luminosity of CBA: precision measurement of the $W^{\pm} - Z^0$ mass difference (with a precision ~0.26 GeV); measurement of the reaction $pp \rightarrow W^{\pm} + \gamma + X$, which measures the magnetic moment of the W and tests the non-Abelian coupling of the gauge theory; W^+W^- pair production which probes the $W^+W^-Z^0$ coupling characteristic of non-Abelian gauge theory; and searches for Higgs particles, etc. CBA will provide the highest sensitivity to any new phenomena up to masses of 300 GeV and is well matched to the mass scale set by the $W^{\pm}$ and Z^0. The ability to measure all the above important processes was studied in great detail using the Monte Carlo program ISAJET. Methods were found which promise to be very sensitive to supersymmetric particles such as gluinos, scalar quarks, and winos (supersymmetric partner to the W). In the latter case, the possibility of polarized protons in CBA may provide a very important handle as they would be produced in parity-violating processes. Another particle worth searching for is the η_T, predicted by technicolor models to lie in the range 200 to 300 GeV.

CBA is of course ideal for studying rare processes. At $L = 10^{33}$ cm^{-2} sec^{-1} it should produce about 5 W's sec^{-1}, 10^4 B mesons sec^{-1}, 10^3 τ leptons sec^{-1}, etc. As an example of what is possible, the use of Si micro-vertex detectors with a small interaction region was investigated and shown to be very promising. It would allow the measurement of the branching ratio of the rare process $B^{\pm} \rightarrow K^{\pm}e^+e^-$ with a sensitivity of 10^{-5} or better. The difficulties of doing experiments at very high rates were studied in detail and it was determined that experiments at luminosities of 10^{33} cm^{-2} sec^{-1} are feasible but require careful planning.

Accelerator Department and CBA Project

INTRODUCTION

The Accelerator Department is responsible for the operation of the major high energy facilities at Brookhaven, principally the Alternating Gradient Synchrotron (AGS) and the CBA construction project. Other work within the Department includes the development of advanced accelerator technology for nonaccelerator applications.

In the AGS, protons are accelerated to 28.4 GeV/*c*, then extracted and steered to five metal targets where they interact and produce secondary particles. Beams of secondary particles are focused and transported by systems of magnets to areas where they are used to perform experiments. The Department oversees the scheduling of these experiments and provides services to non-BNL user groups, e.g., help with setting up heavy apparatus, provision of electronic instrumentation, cryogenic targets, and the use of special facilities such as the Multiparticle Spectrometer (MPS).

The AGS

The acceleration cycle begins with the formation of negative hydrogen ions by electron pickup from a cathode whose work function has been reduced by adsorption of cesium vapor. The negative hydrogen ions are then accelerated down the column of a Cockcroft-Walton preinjector from which they emerge with a kinetic energy of 750 keV. The beam is then transported into the 200-MeV linear accelerator (Linac) where it is accelerated and injected into the AGS. The negative ions are stripped of their electrons by a thin foil at injection.

The AGS is a proton synchrotron of the alternating gradient type. The basic elements of a synchrotron are the ring of magnets which guide the protons around a nearly circular path while applying restoring forces to protons deviating from the central orbit, and the radiofrequency (rf) cavities which provide the energy to accelerate the protons. In the AGS, the transverse slope (gradient) of the magnetic field that a particle in the beam experiences reverses 120 times in one revolution around the machine (hence, "alternating gradient"). This reversing process causes strong focusing, which confines the beam cross section to a relatively small region, thus allowing a much smaller evacuated beam pipe to contain the beam, and smaller magnet gaps to contain the beam pipe, than is possible without the strong focusing. The rf cavities, located at ten positions around the ring, increase the energy of the protons with every pass until, after about two hundred thousand passes and 0.5 sec of time, it has risen to 28.4 GeV. In the AGS, the radio frequency is chosen to be 12 times the revolution frequency, which results in the circulating protons being divided into 12 tight bunches during most of the accelerating cycle. Once full energy is reached, the protons are ejected from the main ring and sent down beam lines to target stations where they can be used for experiments. Then the cycle begins anew.

There are two extraction modes at the AGS. In the slowly extracted beam (SEB) mode, the circulating beam is first debunched and then slowly extracted over many turns. This is accomplished by causing the beam size to slowly increase by exciting resonances in the orbit and gradually "shaving" off some of the beam particles with an electrostatic septum. The extracted proton beam is then split further and directed to external beam lines by a series of septa and magnets which make up the highly efficient

SEB "switchyard." The entire circulating beam is extracted in this manner over about 1 sec. This relatively long time allows experimenters to take data smoothly without overloading their detectors. The total machine cycle requires about 2.5 sec.

While a particular experiment may not be able to use all the protons available from the AGS, the extracted beam can be split into four beams and, hence, serve as many as eight experiments and a test beam simultaneously. Thus, it is usually desirable to accelerate as many protons as possible. The standard available intensity is now greater than 0.9×10^{13} protons per pulse, and a peak intensity of more than 1.25×10^{13} has been achieved.

For experiments that are not rate-limited and, in particular, experiments using a neutrino beam generated by the proton beam, it may be desirable to receive the full beam with its rf time structure intact over a short period. In the fast-extracted beam (FEB) mode, the proton beam is not debunched and is fully extracted in a single turn. In this case, the beam pulse is delivered within 3 μsec. For this mode, the repetition rate is higher than for SEB, with one pulse delivered every 1.6 sec.

Figures 1 and 2 give the accumulated total protons accelerated and the total hours available for doing high energy physics (HEP) experiments over the past several years. As Fig. 1 illustrates, 4×10^{19} protons were accelerated in FY 1982 during 23 weeks of running time. The operating efficiency, defined as the ratio of (HEP hours) to (HEP hours + unscheduled downtime), was 69%. This parameter has remained nearly constant over the past few years despite tightening budgets. During an average week of scheduled running time, 122 hours were available for HEP. Average intensity per pulse was 0.76×10^{13}, 14% higher than in FY 1981. Total protons delivered increased by 29%.

While the AGS is busy accelerating protons to 28.4 GeV, its injector, the 200-MeV Linac, is able to continue cycling, delivering protons to two other facilities, the Brookhaven Linear Isotope Producer (BLIP) and the Chemistry Linac Irradiation Facility (CLIF). The total 200-MeV proton charge delivered to the BLIP in FY 1982 was 0.19 ampere-hour, 10% more than in FY 1981.

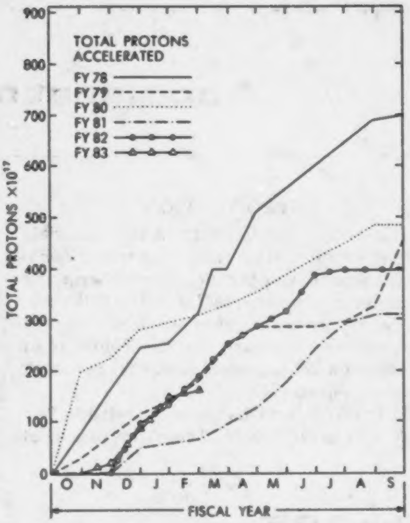

Figure 1. The accumulated total number of protons accelerated each fiscal year since FY 1978.

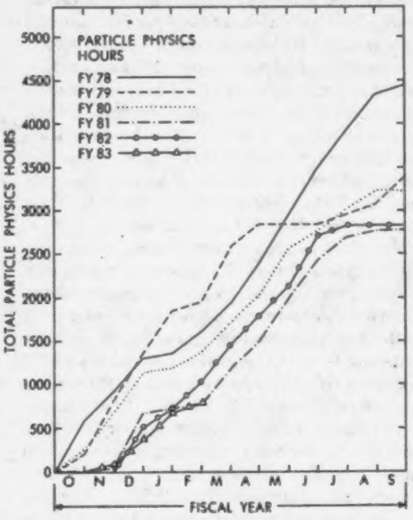

Figure 2. The total hours available for high energy physics experiments since FY 1978.

IMPROVEMENTS TO THE AGS

During the summer shutdown of 1982, several changes of greater than usual scope and significance were accomplished. The most important of these was the changeover to H^- charge exchange injection at the AGS (Fig. 3). This new injection scheme has reduced beam losses and provided higher reliability of the injection systems.Indeed, new intensity records have already been set shortly after restarting the machine with a peak intensity of 12.5×10^{12} protons per pulse and a one-shift (8 hour) average of 11.32×10^{12} per pulse.

By injecting negative hydrogen ions into the AGS and stripping the electrons away by passing the beam through a thin carbon foil inside the ring, a source of protons is created whose position in phase space within the machine acceptance can be held fixed throughout the injection pulse. All the protons can be "overlaid" into the same phase space rather than "stacked" into adjacent phase-space areas as required with the previous H^+ (proton) injection. This approach provides greatly increased flexibility in filling the AGS. As a result, the present intensity limitations may be pushed back, or at least better understood. In addition, the radiation levels in the injection region have been greatly decreased. Previously, 70% of the injected beam was lost during injection. With H^- injection, these losses have dropped to about 10%. The beam current handled by the Linac is thereby reduced, improving reliability and increasing the lifetime of Linac components.

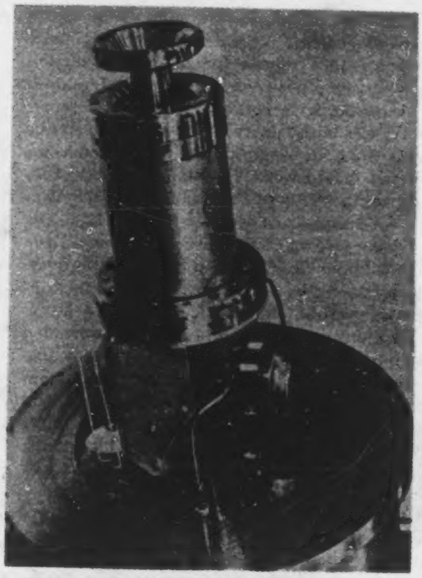

Figure 3. The new H^- source.

With the intrinsically greater simplicity and reliability of the injection system, other factors limiting the beam intensity will come into focus and proper measures can be planned to remedy them in the future. In FY 1983, the radiofrequency acceleration system has become the subject of detailed scrutiny to explore how it limits the intensity of the beam, during capture after injection and during acceleration.

Polarized Proton Acceleration

The most extensive program of modification now under way in the AGS Division is the effort to accelerate polarized protons. The spins of the protons accelerated in the AGS are randomly oriented. During the late 1970s, some extremely surprising experimental results were produced at the ZGS, a 12-GeV proton accelerator at Argonne National Laboratory, using polarized protons, i.e., protons whose spins were preferentially aligned in a single direction. With the objective of studying polarized proton interactions at the higher energies available at the AGS, a collaborative effort has been mounted by BNL and groups from the University of Michigan, Argonne, Yale University, and Rice University. Essentially every step in the accelerating process poses challenging problems.

The polarized ion source has achieved 0.5 μA of beam on the test stand, and, with an upgraded cesium gun which is under construction, it is expected to deliver several microamperes, as required by the program, in the near future.

Acceleration from source to Linac will take advantage of recent advances in low beta accelerators, using an RFQ, an rf cavity with vanes shaped to produce focusing and accelerating forces on the protons, rather than a Cockcroft-Walton preaccelerator.

In order to maintain the polarization of the protons through the acceleration cycle, a number of schemes must be employed to avoid a series of 50 imperfection and 8 intrinsic depolarizing resonances. The worst of these are the intrinsic resonances which are caused by the same strong focusing magnetic fields that allow the AGS to accelerate its beams. The effects of these resonances can be suppressed by moving through the resonance condition rapidly, which can be accomplished by suddenly changing the quadrupole field that particles in the beam experience.

Four of the 12 pulsed quadrupole magnets to be used for polarized proton acceleration were installed in the AGS and another 8 are expected to be installed in 1983. These magnets will permit a rapid variation of the vertical "tune" of the ring to maintain proton polarization while crossing the 8 intrinsic depolarizing resonances during the acceleration cycle.

An engineering prototype pulsed quadrupole power supply is being tested and plans are being made for the manufacture of 6 of the required 12 quadrupole modulators in FY 1983. With 6 power supplies, polarized protons can be accelerated to about 20 GeV which will permit the start-up of the polarized proton program after the end of FY 1983. Six more power supplies to be assembled later will permit extension of the energy to 26 GeV. Beam diagnostic equipment in the Linac and the AGS will be adapted for the low polarized proton intensity. Polarimeters will be installed in the LEBT (at 20-keV energy), in the Linac-AGS transport line (200-MeV energy), in the AGS vacuum chamber (up to 26 GeV), and in the external beam line near the D target (top energy). These polarimeters will permit determination of the polarization of the beam as a function of energy throughout the acceleration and spill cycle.

Instrumentation

With a view toward the commissioning of the new H^- injection system, the development of a polarized proton beam capability, and the future needs of the CBA injection system, new beam diagnostic instrumentation was developed and tested in the AGS in FY 1982. The Internal Profile Monitor, a device using the induced residual gas ionization to obtain a profile of the beam distribution in the AGS, was installed and tested successfully. This diagnostic tool permits a quantitative study of the AGS beam size as a function of time in the acceleration cycle. The capabilities of the extracted beam profile monitors in the FEB line were expanded and a systematic measurement of the extracted beam emittance has been obtained with new devices, multiwire secondary emission monitors. Both the internal profile monitor and the external beam profile monitors are extremely valuable for conventional operation. They will be essential for polarized proton operation, where vertical beam size affects the strength of depolarizing resonances, and for CBA injection, where beam emittance affects the final luminosity.

It is expected that in FY 1983 an automatic betatron tune measuring system will be developed for the AGS. In conjunction with the new beam profile monitor, it will then be possible to test various tune operating points in the AGS as a function of time with a view to minimizing transverse beam dilution. In polarized beam operation, the tune is carefully programmed throughout the acceleration cycle, and a convenient tune measurement system is vital to the success of that program.

Other Improvements

A major event during the summer shutdown was the repair of the Siemens motor and generator rotors in a General Electric service shop in New Jersey. These components had developed weaknesses in the coil windings and the repair work was both timely and successful. At the same time, the Westinghouse motor generator set, which had served the AGS prior to the conversion in 1970, was recommissioned with a rewound stator. At the start of FY 1983, the Siemens set was back in operation, and the Westinghouse set (with about half the duty-cycle capability of the Siemens) was in fully operational standby status.

Replacement of a number of badly corroded vacuum chamber bellows in the AGS was also accomplished during the shutdown. Still more of them will need to be replaced in FY 1983. The ring vacuum system was upgraded with a gauge system, and the monitoring of the ion pumps was changed to allow better localization of areas with high leak rates.

A fast kicker magnet has been installed and beam has been extracted to serve the D line with a single bunch of beam, simultaneously with the extraction of the remaining 11 bunches to the neutrino experiments in the north area

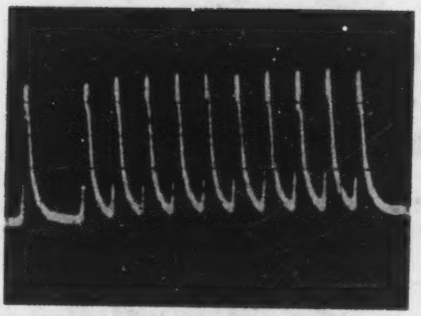

Figure 4. The proton beam bunches extracted in the FEB line following the extraction of the second bunch in the SEB.

(FEB). The kicker magnet is a duplicate of the one serving the FEB, but the excitation pulse is very short (400 nsec). This is necessary in order to cleanly extract the single bunch for Exp. 745, a test of quantum electrodynamics in muonic helium, while not disturbing the remaining 11 bunches which are destined for fast extraction to the neutrino area. Figure 4 shows the 11 remaining bunches in the AGS following extraction of the second bunch.

In the rf system, shorting switches were installed across the accelerating gaps. These switches are activated during the flattop while a slow spill is being delivered to the external beams. This is done to suppress the undesirable high-frequency modulation which adversely affects the duty cycle of the spill. For many experiments the absence of spill modulation improves the data-taking capability.

NEUTRAL BEAM DEVELOPMENT

The objective of the program is the development of high energy steady state neutral beams for future fusion devices, for heating experiments in tokamaks and mirror machines, for current drive in tokamaks, and for on-line plasma diagnostics. The BNL Neutral Beam Development Group currently has concentrated its efforts on developing high-density negative deuterium sources and plasma neutralizers, the latter as an alternative to laser neutralizers. The ion sources are based on the direct extraction of negative ions from a plasma surface system, either without or with plasma injection from an independent hollow cathode discharge; hollow cathode arcs also serve as the plasma source for the neutralizer.

During the past year, ion studies have been concentrated on the system with hollow cathode discharges, where plasma generation and negative ion production are separated and can be independently controlled. A true steady state operation (several days) of the plasma generator and the converter electrode has been achieved; more than 0.2 A of H^- ions has been extracted over several hours, with peak values of 0.5 A. Plasma uniformity and gas efficiency have been greatly improved by changing the electrode shape. A new source module has been fabricated to produce a flat sheet of plasma in front of the converter; it should yield a ribbon H^- beam with a line current density of 6 A/m, with a gas efficiency better by a factor 3 than any existing source. The geometry of the source has been chosen to match the LBL accelerator.

Plasma neutralizers for negative ions have been studied further and a 1-m-long system is in fabrication. It will be used to determine neutralization efficiencies of hydrogen and other negative ions, in cooperation with the BNL Physics Department.

FUTURE PLANS

A preliminary design study for an accumulator ring between the Linac and the AGS was completed in early 1983. The accumulator ring is envisioned as part of a two-pronged approach to increasing the polarized proton beam intensity above the limit of about 10^{10} protons per pulse provided by the presently conceived ion source. After commissioning of the present ion source and the initial polarized proton physics program, long-term research and development will be directed at improving the intensity of polarized ion sources by two or more orders of magnitude. The accumulator will provide more than an order of magnitude above whatever is achieved with the ion sources. Moreover, its magnet lattice will be designed to permit, in a subsequent expansion phase, the acceleration of protons to about 1-GeV kinetic energy prior to injection into the AGS. This will make it possible to raise the space-charge limit on the AGS intensity.

Planning and Support of the Experimental Program

The Experimental Planning and Support (EP&S) Division is responsible for the operation of the AGS experimental research program. This responsibility includes the development and execution of both long- and short-range schedules as outlined by the Director. The EP&S staff carries out the planning and construction of particle beams; installation and servicing of large experimental equipment such as spectrometer magnets, hydrogen targets, and large particle detectors; maintenance and operation of beam separators and cryogenic devices; installation and maintenance of electrical power and cooling water systems; maintenance of a large pool of electronics equipment for experiments (HEEP); safety review of experimental setups; design of new beams and experimental facilities; and development of new detectors and electronics, all as required to support the research activities of guest and resident scientist users. Operational crews are maintained on a 24-hour, 7-day-per-week basis to operate, service, and provide safety surveillance of the experimental areas and equipment. The EP&S Division also is responsible for the operation of the On Line Data Facility (OLDF).

Twelve experiments were run and three were completed in FY 1982 during the 12 weeks of the counter program and the 11 weeks of the neutrino program. Seventeen experiments are expected to run in FY 1983 during the 14 weeks of the counter program and the 7 weeks of the neutrino program. The experimental area layout is illustrated in Fig. 5, and the characteristics of the beams used to support the program are given in Table I. Table II describes both the completed FY 1982 program and the anticipated FY 1983 program.

The major EP&S projects can be classified into two categories: experimental area operations and support; research and development projects.

Beam	Experiment	University
A1	747	BNL/CCNY
A1	769	Notre Dame/Brandeis/BNL/CCNY/Duke
A2	Test Beam	Many Users
A3	749	BNL/Yale
B1	Test Beam	Many Users
B2	751	Brandeis/SE Mass/Notre Dame/Duke
B2	771	BNL/FSU/Ind/SE Mass
B4	722	BNL
B5	766	Columbia/Mass/Mexico
C1	755	BNL/Minn/SE Mass
C2	758	LASL/BNL/FSU/Houston/Rutgers/Wm&Mary
C2	759	CMU/Houston/BNL
C2	774	Houston/BNL/N Mex/Vassar
C4	723	Wm&Mary/Boston/CMU/CIT/Wyo
C6	772	BNL/Case West/Maryland/Syracuse
C8	767	BNL/Houston/Penn State/Rice
C8	702	Yale/BNL/Mt. Holyoke/Pitt
D1	748	Mich/BNL/Miami/Maryland/Copenhagen/Notre Dame/ETH (Zurich)
D2	745	Columbia/CERN/BNL/
D4	754	Bell Labs/BNL/Wm&Mary/G. Mason/Virgina St
U	734	BNL/Penn/Brown/KEK/Tokyo/Osaka/Stony Brook
U	775	BNL/Brown/Penn/KEK/Stony Brook/Tokyo/Osaka/Irvine
U	779	BNL

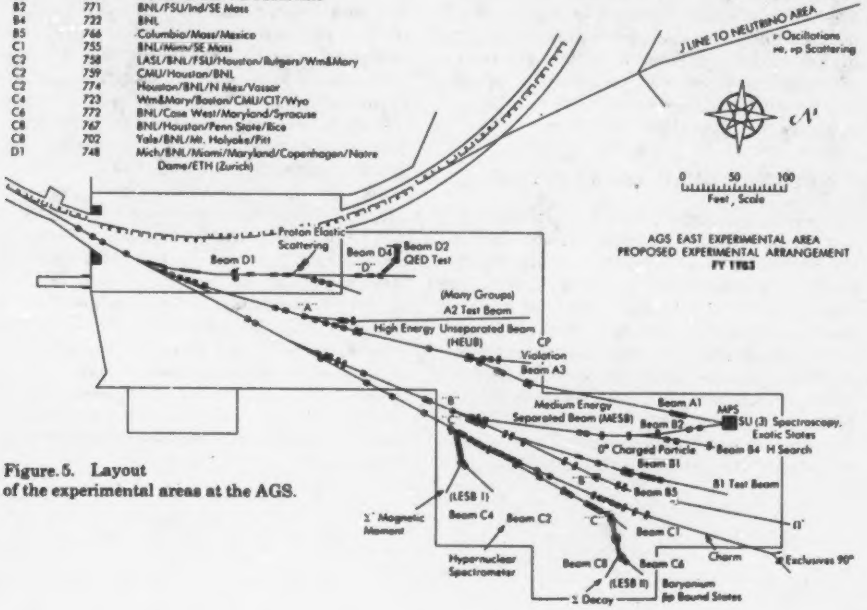
J LINE TO NEUTRINO AREA
ν Oscillations
νe, νp Scattering
0
50
100
Feet, Scale
AGS EAST EXPERIMENTAL AREA
PROPOSED EXPERIMENTAL ARRANGEMENT
FY 1983
Proton Elastic Scattering
Beam D1
Beam D4
"D"
Beam D2
QED Test
(Many Groups)
A2 Test Beam
"A"
High Energy Unseparated Beam (HEUB)
CP Violation
Beam A3
"B"
"C"
Medium Energy Separated Beam (MESB)
Beam A1
MPS
Beam B2
SU (3) Spectroscopy, Exotic States
0° Charged Particle
Beam B4 H Search
Beam B1
B1 Test Beam
"B"
Beam B5
Ω⁻
(LESB I)
Σ⁻ Magnetic Moment
Beam C4
Beam C2
"C"
Beam C1
Charm
Exclusives 90°
Hypernuclear Spectrometer
Beam C8
Beam C6
(LESB II)
Σ Decay
Baryonium p̄p Bound States

Figure. 5. Layout of the experimental areas at the AGS.

Table I
BNL Beams Operational
January 1983

Beam	GeV/c	$\pm\frac{\Delta p}{p}$ (%)	Prod. Angle	Ω (msr)	K^+	K^-	p	$\bar{p}$	π^+	π^-	@ GeV/c	Purity	Remarks
Separated Beams for General Use					Flux in thousands/10^{12} protons on target								
B4	1.5-6(K) 1.5-9($\bar{p}$)	3	3°	0.3	270	120	2×10^4	100	4×10^4	2×10^4	4	$\pi^-/K^-\sim8$ $\pi^-/\bar{p}\sim\epsilon$	Usually 2×10^{12} ppp; L = 81 m
C2,C4	<1.1	2	10.5°	2.8	40	12	5×10^4	2	8×10^4	8×10^4	0.75	$\pi^-/K^-\sim10$	Usually 2×10^{12} ppp; L = 15 m
C6,C8	<0.8	2.5	5°	15.0	300	80	1.4×10^3	14	6×10^3	6×10^3	0.7	$\pi^-/K^-\sim20$	Usually 2×10^{12} ppp; L = 15 m
Separated Beams for Fixed Facilities													
B2	(Same characteristics as B4)												MPS
Unseparated Charged Beams for General Use													
B1	5-24	3	0°	0.3	2500	700	1.8×10^5	200	6×10^4	3×10^4	10		Usually 2×10^{12} ppp; L = 75 m
C1	5-24	5	0°	0.8	900	400	3×10^4	30	1×10^4	2×10^4	13	$\mu^-/\pi^-=.03$	Usually 2×10^{12} ppp; L = 61 m
Unseparated Charged Beams for Fixed Facilities													
A1	5-24	1.5	0°	0.2						1000	22		MPS: L = 130 m; 10^{13} ppp; 25-cm Be target
Neutral Beams for General Use								K_L	n				
A3*	1-28		0°	0.0036				2000	10^5		1-28		<10^{13} ppp; alternates with A1; L = 8 m; design intensity
Muon Channel													
B5	1-28		0°	0.01					3×10^5		1-28		10^{13} ppp t[illegible] al; L = 2.8 m; design intensity
Meson Channel													
D2, D4	1-0.2(π) 0.05-0.15(μ)	9(π)	55°(π)	50(π)		2000					0.10		Flux in 100 cm^2 with $\Delta p/p=\pm2\%$; design intensity
Neutral Beam for General Use						ν	$\bar{\nu}$						
U						$10^7/\mathrm{m}^2$	$7\times10^6/\mathrm{m}^2$					9×10^{12} ppp typical	Fast spill, flux av over 0.7-m radius, peaks at 1.5 GeV/c

*A3 has been converted to a neutral beam for FY 1982.

Table II
Utilization of Beam Lines

Beam	Exp. No.	Institutions Description of Experiment	
A1	747	BNL/CCNY Study of ϕ production from $\pi^- p$ reactions, including $\pi^- p \rightarrow \phi\phi n$, with a search for resonances in the $\phi\phi$ system (glueballs).	To be completed in FY 1983.
A1	769	Notre Dame/Brandeis/BNL/CCNY/Duke A search for glueballs and other meson states. Study the reactions $\pi^- p \rightarrow n\,K_s^0K_s^0\eta^0$ and $\pi^- p \rightarrow n\,K_s^0K_s^0\pi^0$ at 21 GeV/c with a lead glass hodoscope in the MPS.	To begin FY 1984.
A3	749	Yale/BNL Test milliweak CP-violation models by accurately measuring difference in the ratio of charged to neutral two-pion decays for K_s and K_L meson decays.	To be completed in FY 1983.

Table II (Continued)
Utilization of Beam Lines

Beam	Exp. No.	Institutions Description of Experiment	
B2	771	BNL/FSU/Ind/SE Mass Study of E meson characteristics in $\pi^- p$, $K^- p$, and $\bar{p}p$ interactions in the MPS. The possible glueball and strangeonium components will be distinguished by the production reaction.	To be completed in FY 1983.
B2	751	Brandeis/SE Mass/Notre Dame/Duke Measurement of the radiative hyperon decays $\Xi^0 \to p\gamma$, $\Xi^0 \to \Lambda\gamma$, and $\Omega^- \to \Xi\gamma$ in the MPS with a lead glass hodoscope.	To begin FY 1983.
B4	722	BNL A second-generation search for exotic six-quark states in the reaction $p + p \to K^+ + K^+ + X$. Exotic states would be observed as missing mass peaks recoiling against the two K^+'s.	To be completed in FY 1983.
B5	766	Columbia/Mass/Mexico Study of Ω^- production from $np \to \Omega^- X$ resonances.	Continuing into FY 1983
C1	726	NYU/BNL Search for charm in hadronic interactions near threshold. The reactions: $\pi^- p \to D^{*-} B_c^+ \quad (B_c^+ = \Lambda_c^+, \Sigma_c^+, \ldots)$ $\qquad\quad \hookrightarrow \bar{D}^0 \pi_s^-$ $\qquad\qquad\quad \hookrightarrow K^+ \pi^-$ will be studied. The final two decay particles will be analyzed in a large-aperture spectrometer, with sensitivity estimated to better than 20 nb.	To be completed in FY 1983.
C1	755	BNL/Minn/SE Mass Study of hard quark-quark scattering in two-body exclusive reactions at 90^0 in the center of mass. $\pi^- p \to p\pi^-$, $p\rho^-$, pA_2^-, $\pi^+\Delta^-$, $K^+\Sigma^-$, K^+Y^{*-}, ΛK^0.	To be completed in FY 1983
C2	758	LANL/BNL/FSU/Houston/Rutgers/Vassar/Wm&Mary The (π^+K^+) reactions as a new tool for the study of hypernuclear structure. The reaction $\pi^+ + n \to K^+ + \Lambda$ will be used to produce hypernuclei at higher momentum transfers than is possible with the often used $K^- + n \to \pi^- + \Lambda$ process. This should make heavier nuclei and higher spin states more accessible.	To be completed in FY 1983.
C2	759	CMU/Houston/BNL A study of the weak decay modes of the hypernucleus ${}^{12}_{\Lambda}C$.	To be completed in FY 1983.
C2	760	MIT/BNL/Torino/Houston/NYU/Vassar/Peking Spin dependence of the Lambda Nucleus interaction determined by observation of hypernuclear γ rays. The hypernuclei to be studied are ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, and ${}^{16}_{\Lambda}O$.	Completed FY 1983.
C2	774	Houston/BNL/N. Mex/Vassar Search for Σ^- hypernuclear levels in ${}^4He$	
C4	723	Wm&Mary/BU/CMU/Caltech/Wyo Precision measurement of the Σ^- magnetic moment by the exotic atoms technique, using a stopping K^- beam: $K^- p \to \Sigma^- \pi^+$, with the Σ^- captured in a high Z material. Observation of a monoenergetic π^+ tags the presence of the Σ^-, and the μ_{Σ^-} is obtained by measurement of the hyperfine splitting in the transition x ray.	To be completed in FY 1983.

Table II (Continued)
Utilization of Beam Lines

Beam	Exp. No.	Institutions Description of Experiment	
C6	762	BNL/Mich State/Syracuse/Temple Search for narrow structures in the $\bar{p}p$ annihilation cross section from 1900 to 1960 MeV, with 2.5-MeV resolution.	Completed FY 1982.
C6	772	BNL/Syracuse/Case Western/Maryland Search for $\bar{p}n$ bound and resonant states, in particular, the reported effects at 1795 and 1987 MeV. The reaction $\bar{p}d \to p + \bar{p}n$ is studied with a recoil proton spectrometer.	To be completed in FY 1983.
C8	702	Yale/BNL/Mt. Holyoke/Pitt Measurement of the asymmetry in the decays of polarized hyperons produced from a polarized target. Measurement of the Σ^+ decay parameters in $\Sigma^+ \to n\pi^-$ decays and Σ^+ in $\Sigma^+ \to p\pi^0$.	To be completed in FY 1983.
C8	767	BNL/Houston/Penn State/Rice Development of a low energy antineutron source and measurement of $\bar{n}p$ annihilation cross section near $\bar{N}N$ threshold. The construction of an antineutron beam will permit the study of the $\bar{N}N$ interaction at very low energies where dE/dx limits the usefulness of $\bar{p}$ beams. $\bar{n}$'s will be produced by 500 MeV/*c* in the charge-exchange reaction $\bar{p}p \to \bar{n}n$.	To begin FY 1983.
D1	748	BNL/Mich/Miami/Copenhagen/Maryland/Nctre Dame/ETH (Zurich) Measurement of the analyzing power in proton-proton elastic scattering as a function of s and $p_\perp^2$ using a polarized proton target at several proton beam energies up to 28 GeV.	To be completed in FY 1983.
D2	745	Columbia/CERN/BNL A precise measurement of the 3d → 2 p transition in muonic helium as a test of quantum electrodynamics. A high-power CO_2 laser is employed to induce the transition following a muon stopping in helium gas. The emitted 9.75-keV x ray is detected with a solid state device.	To begin FY 1983.
D4	754	Bell Labs/BNL/G. Mason/Virginia State/Wm&Mary Study of positive muon depolarization in doped aluminum. The measurements are intended to discriminate among various models of μ^+ motion in metals. These results are needed for future use of the μ^+ spin rotation technique in more complex condensed matter systems.	To begin FY 1983
U	775	BNL/Brown/Penn/KEK/Osaka/Stony Brook/Tokyo (INS)/ UC Irvine Search for neutrino oscillations via $\nu_\mu \to \nu_e$ transitions, using a narrow-band ν_μ beam and the E734 detector.	To begin FY 1983.
U	734	BNL/Brown/Penn/KEK/Osaka/Stony Brook/Tokyo (INS) Measurement of elastic scattering of neutrinos from electrons and protons. These are weak neutral current processes. The outgoing electron or proton in the reactions $\nu e \to \nu e$ $\nu p \to \nu p$ is identified by its characteristic behavior in a large aluminum-scintillator-proportional wire counter detector.	Completed FY 1983.
U	779	BNL Nuclear spectroscopy and nuclear reaction studies. 28-GeV/*c* protons will irradiate thin targets, producing new or little-studied neutron-rich nuclides below thorium.	To begin FY 1983.

EXPERIMENTAL AREA OPERATIONS AND SUPPORT

Highlights of the program in FY 1982 include 11 weeks of running in the North Area for the ν–e elastic scattering group, E734 (BNL/Penn/Brown/Osaka/Stony Brook/KEK/Tokyo). They acquired 80 νe events ($E_e > 200$ MeV), 3000 νp elastic events ($Q^2 > 0.04$ GeV^2), and 20 νe elastic scatters ($E_e > 200$ MeV). In the East Area A1 line, E747 (BNL/CCNY) found evidence for composite gluon systems (glueballs). Using the improved MPS, they observed resonances in the $\phi\phi$ system by detecting the decays of the two ϕ's into K^+K^- pairs. In the C1 line, E726 (NYU/BNL) completed a search for hadronic charm production. In LESB I, E760 (MIT/BNL/Torino/Houston/NYU/Vassar/Peking) completed a study of the spin dependence of the lambda-nucleus interaction by observing hypernuclear gamma rays. Also in this beam, E723 (Wm&Mary/BU/CMU/Caltech/Wyo) measured the magnetic moment of the Σ^- hyperon. They studied the hyperfine splitting in exotic atoms produced by stopping K^-. Their results will complement those obtained at higher energies which measure the spin precession directly. In the LESB II, E762 (BNL/Mich State/Syracuse/Temple) completed a search for narrow structures in the $\bar{p}p$ system between 1900 and 1960 MeV, and E702 (Yale/BNL/Mt. Holyoke/Pitt) continued their study of the asymmetry in the decays of polarized $\Sigma^\pm$ hyperons produced by K^- incident on a polarized proton target. The first experiment in the D1 line, E748 (BNL/Mich/ANL/Miami/Copenhagen), was begun. It is a study of the analyzing power of pp elastic scattering, using a polarized target, and is a precursor to the development of this area for use with polarized protons.

The stopping muon beam D2 was installed and commissioned early in FY 1983. Experiment 745 (Columbia/CERN), a test of quantum electrodynamics in muonic helium, will have a test run in FY 1983, as will E754 (Bell Labs/BNL/Wm&Mary/G. Mason/Virginia State), the muon spin rotation experiment.

A new test beam was under construction in the B1 area early in FY 1983. It will provide particles up to 20 GeV/*c* for several groups which will test detectors in FY 1983.

Installation of quadrupole magnets in Beam C1 behind Exp. 726 greatly improved the beam optics for Exp. 755 (BNL/Minn/SE Mass) (Fig. 6) which is in tandem with the apparatus of E726 which was completed in FY 1982.

A 5-in.-gap electrostatic beam separator was built and installed in the LESB II, replacing the 6-in.-gap separator whose performance had greatly deteriorated in FY 1982 running. A marked improvement in performance and reliability resulted. A 2-in.-gap separator doublet was installed in the MESB, providing greatly improved beam purity for E722 (BNL), a search for six-quark exotics, and Exp. 771 (BNL/FSU/SE Mass/Ind), a search for gluonium states. The hypernuclear spectrometer underwent a major upgrade early in FY 1983, providing nearly an order of magnitude increase in particle flux for E758 (LANL/BNL/FSU/Houston/Rutgers/Vassar/Wm&Mary) and E759 (CMU/Houston/BNL). A new narrow-band neutrino horn was designed for the long base line neutrino oscillation experiment, E776 (Columbia/Ill/Johns Hopkins/NRL), which is under construction in the North Area. A high-

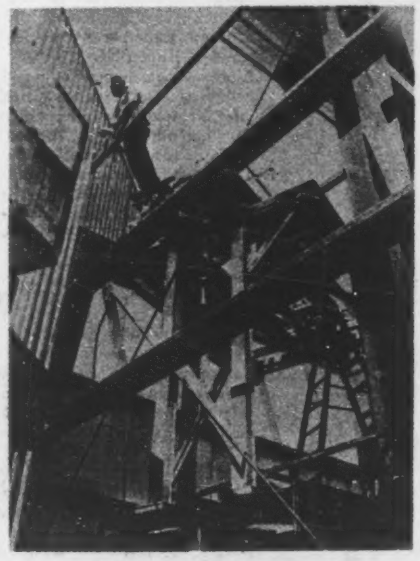

Figure 6. Experiment 755 (BNL/Minn/SE Mass) under construction.

intensity beam was designed for Exp. 777 (Yale/BNL/Wash), a rare kaon-decay experiment which will test technicolor theories.

RESEARCH AND DEVELOPMENT

Development work was concentrated in multiwire secondary emission chambers which were used for emittance measurements in the extracted beam to the neutrino area and in further development of FASTBUS in collaboration with Exp. 749 (Yale/BNL).

ADVANCED TECHNOLOGY APPLICATIONS DIVISION

During the past year the 1000-MVA superconducting power transmission cable Test Facility has been operated for three running periods, each of about two weeks' duration. The system performance has been measured with simultaneous voltage and current excitation up to the rated levels of 80 kV and 4100 A, corresponding to 138 kV, 1000 MVA on a three-phase basis. In addition, the cables have been energized up to the 30-minute emergency rating of 6000 A.

A first full-wall trial cable was constructed of the fully synthetic tape insulation developed by Brookhaven. Tests of oil compatibility, oil impregnation, and high-voltage performance have been carried out.

A 300-ft-long cable will be made in May 1983, for installation in the outdoor Test Facility. Methods of terminating the cable are under investigation. The cable is rated for 230-kV service.

The CBA Project

The Colliding Beam Accelerator (CBA) project which was designed to accelerate protons at energies up to 400 GeV was canceled late in 1983. Cessation of the construction project was predicated upon the belief of the high energy physics community that every effort must be made to design and build, in the United States, a superconducting super collider (SSC) with proton energies in excess of 2 TeV (2000 GeV). This decision was made after it was apparent that Brookhaven could finish the construction of the CBA on time and on budget. Although we believe that such a decision was not in the best interest of high energy physics, we have joined the efforts to plan for the SSC and we expect to play a leading role in magnet design for the new machine. In addition, there is a strong move to take advantage of the construction already completed and the expertise on hand to build a heavy-ion colliding beam accelerator which will again make Brookhaven a unique center for an important area of physics.

Although what follows was aimed at the CBA, most of it will also apply to the proposed heavy-ion accelerator.

SUPERCONDUCTING MAGNETS

As reported in the previous HIGHLIGHTS, 1981 was devoted to implementing the modified two-layer superconducting magnet design devised by R.B. Palmer, i.e., a design based on a cabled conductor similar to that used at Fermilab, wound in a two-layer coil prestressed by a laminated split iron yoke. The magnet is shown schematically in Fig. 7. In light of the fine performance of the initial short and full-length model dipoles tested during the summer and autumn of 1981, this magnet design was formally adopted in December of that year.

The spring of 1982 saw additional prototype dipoles constructed and tested at an accelerated pace, with the Magnet Division's initial goal of testing six full-length dipoles by March successfully achieved on time. All dipoles, when tested in liquid helium at a bath temperature of ~4.5 K, reached a quench "plateau" of approximately 55 kG with very modest "training," independent of ramp rates well in excess of the maximum CBA ramp rate of 8 A/sec. This rate corresponds to 8 minutes' current rise time from the CBA magnet injection current of 264 A (3.9 kG)

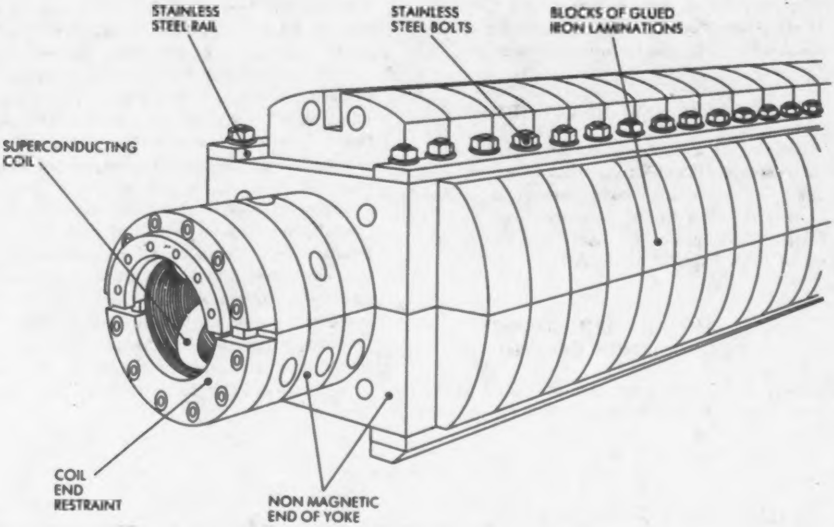

Figure 7. Schematic of superconducting dipole magnet end configuration.

to the operating current of 3770 A (52.8 kG) at 400-GeV proton energy. When tested at temperatures near 3.8 K (the maximum CBA design operating temperature), the magnets reached fields of ~58 kG, and ~60 kG in the 3 K temperature region, the lowest temperature attainable in these magnet tests.

The first prototype quadrupole magnet was tested as well; it also exceeded design operating specifications by a substantial margin with little training. Other R&D efforts during the spring of 1982 concentrated on the following areas. 1) Magnet construction details and assembly procedures necessary to ensure that the magnets would satisfy the stringent CBA tolerances on field quality were studied. This program centered initially on the construction of a series of dedicated short (~2 m long) dipoles. An important component of the program was the fabrication of a high pressure molding fixture for achieving dimensional uniformity of assembled magnet coils. 2) Quench protection studies were initiated to ensure that the magnets are able to safely absorb their own stored energy (1 MJ in the case of a dipole at full field) during a quench without damage or deterioration in performance. 3) Various alternative superconducting "trim coil" designs were studied; these are located within the main dipole or quadrupole coils, intended to correct for iron saturation and superconductor magnetization effects and to aid in steering the proton beams in the accelerator. 4) Finally, construction of a short demonstration dipole of the so-called 2-in-1 design was initiated. Such a magnet would contain a pair of dipole (or quadrupole) coils, belonging to adjacent proton rings, side-by-side in a common iron yoke, and was devised to achieve significant cost savings by halving the required number of magnet yokes and cryostats.

By the end of the summer of 1982, fairly exhaustive quench protection studies on full-length dipoles (including the first dipole tested horizontally in the forced-flow supercritical helium cooling mode intended for the CBA) had verified that the magnets appear to have an adequate margin of safety from quenching under "worst case" quench conditions visualized in the accelerator. Even so, it was considered prudent to incorporate a quench protection system;

therefore, a "passive double diode" protection scheme was devised and adopted for subsequent deployment in all magnets. Its function is to divert current from the quenching half coil in a magnet, thereby effectively bypassing the energy in the other magnets around it. A trim coil design was adopted, wound in two layers from a 7-strand superconducting cable, prestressed by high-strength Kevlar filamentary wrap. Having been first tested in several short dipoles, a full-length version of the trim coils was tested with satisfactory results in midsummer. Finally, the 2-in-1 dipole, DCM-1, had also been tested in several stages by the end of the summer, providing proof-in-principle of this interesting and alternative magnet approach.

During the remainder of 1982, further regular (i.e., 1-in-1) prototype dipoles and quadrupoles were tested in liquid as well as in supercritical helium. One dipole reached a record field level of 62.2 kG in liquid at ~3.4 K. The field quality program culminated with the first long dipole, explicitly constructed with this as an objective, successfully tested. Moreover, the autumn of 1982 marked an important new milestone, namely, the start of installation of prototype magnets in the CBA tunnel. The first member of the Full Cell, comprising six dipoles and two quadrupoles, was transported to Sextant 5 of the tunnel on October 8—two weeks short of the anniversary of the testing of the first full-length dipole. By the end of December, five dipoles and one quadrupole had been installed and were in the process of being interconnected. The Full Cell would provide an important systems test, including cryogenics, vacuum, and electrical systems, needed for operating a string of magnets in the CBA tunnel environment. Equally important, it would test magnet installation procedures.

On December 21, P. Reardon, the CBA Project Head, announced a major decision on the question of adopting the 2-in-1 magnet design, noted earlier, for the CBA. It had been decided that, although this magnet design appears feasible and offers a promising approach for future accelerators, it would not be adopted for the present effort. The 1-in-1 magnet had met the specifications for a proton-proton Colliding Beam Accelerator and would be retained as the basic superconducting magnet for the CBA. While one full-length 2-in-1 demonstration dipole was in the assembly stage at that time, it would be completed and tested on a low-priority basis. Thus, as the year ended the Magnet Division was poised to concentrate its efforts on the 1-in-1 magnet.

The first quarter of 1983 saw the attainment of several very important milestones in the CBA superconducting magnet program, well ahead of schedule. The most dramatic event was the initial powering of the Full Cell (Fig. 8) to the operating field of 52.8 kG on February 25, with the final two magnets installed and all remaining interconnections having been completed without delay the previous month. The net time required to cool down the cell was three days. Following a series of cryogenic and electrical measurements, a long-term test commenced, in which it was intended to cycle the string of magnets to full field a number of times representing a significant fraction of those expected over the CBA lifetime. At the end of March the magnets had been cycled approximately 100 times at the maximum CBA operating ramp rate. In addition, the cell had operated at full field in the dc mode for a total of approximately 40 hours.

The second milestone, reached in mid-February, was the testing of the eighth successive dipole to meet field quality specifications, thus achieving a major goal of the R&D plan established the previous year—namely, the demonstration of field quality in eight out of ten "identical" dipoles constructed to the stringent CBA design specifications by the end of the first quarter of 1983. Furthermore, by that date the tooling necessary for magnet production was on hand.

CONVENTIONAL CONSTRUCTION

October 28, 1978, marked the official groundbreaking for the conventional construction phase of the project, and actual site clearing took place in January 1979. The entire main magnet enclosure, including earth shielding, required approximately 28 months and was completed in August 1981. As originally planned there were to be four experimental halls and two open areas where experiments could be installed in temporary structures. The first effort was the construction of the Wide Angle Hall at the 6 o'clock location; it was completed in April 1981.

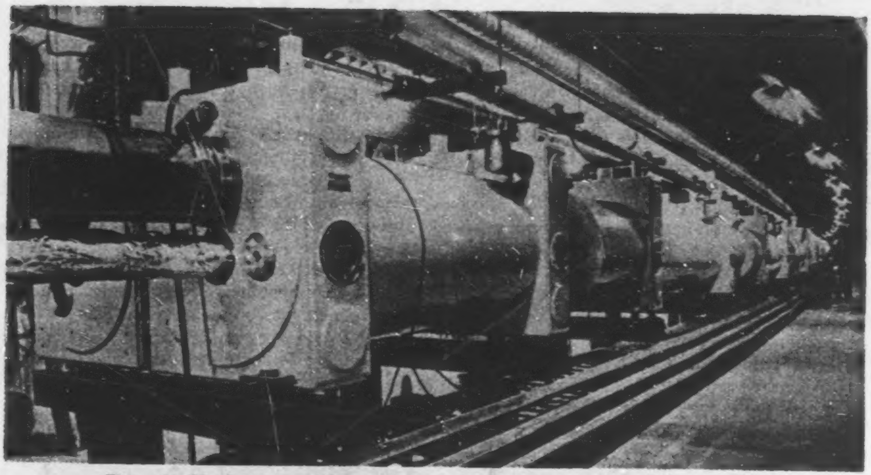

Figure 8. The first string of CBA magnets being prepared for testing in the tunnel.

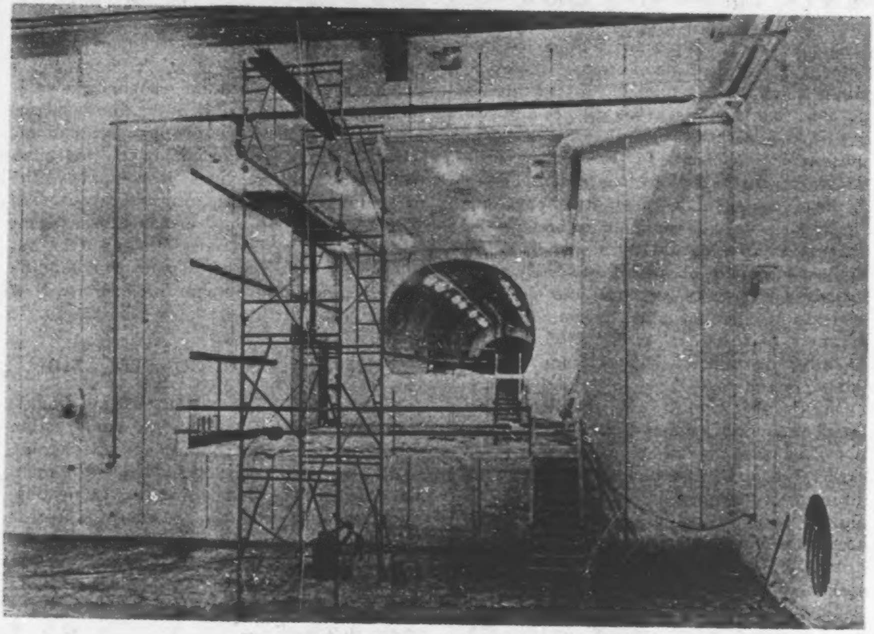

Figure 9. The interior of the Major Facility Hall.

It is sized to house large-aperture spectrometers for identification and analysis of particles of high transverse momentum. The open area at 4 o'clock followed and was completed two months later. The Major Facility Hall at 8 o'clock, the largest of the halls built to date and designed to accommodate a large class of major general purpose detectors, was completed in May 1982. It is shown in Fig. 9. The fourth experimental area, the Narrow Angle Hall (2 o'clock), designed to house a typical single-particle spectrometer capable of particle identification at very high energies, was completed in the autumn of 1982. By that time the injection beam tunnels from the AGS to the CBA magnet enclosure were also completed.

The Service Building Complex was designed and constructed under two separate contracts. Phase I included the Cryogenic Wing and the Compressor structure; these were completed in August 1981 and are depicted in Fig. 10. Phase II covered the four-story main building, to house control and computer rooms, office space, shops and laboratories, and the Rf/Power Supply Wing. Work on this building got under way in July 1981, and completion is scheduled for the autumn of 1983. At the time of writing, with site work and installation of utilities also in progress, approximately 75% of the physical plant is complete or under contract. Major elements of the uncompleted portion are the experimental areas at 10 and 12 o'clock, which have been deferred until more construction funds are available. Area 10 is currently envisioned as an open area similar to the existing one at 4 o'clock, and for Area 12 an extra-large experimental hall is contemplated.

Rf Systems

Two rf systems are required to accumulate and accelerate the design current of 8 A in the CBA. A 6-m stacking cavity was fabricated and successfully tested. Tests of a model accelerating cavity, which is shown in Fig. 11, were successful. The design of both the stacking and accelerating systems is complete and many components are under construction or on order.

Vacuum

The design parameters of the ring vacuum and the magnet insulating vacuum were achieved earlier a) in tests on 45 m of beam tube in which pressures $<10^{-11}$ Torr were routinely obtained and maintained for several months

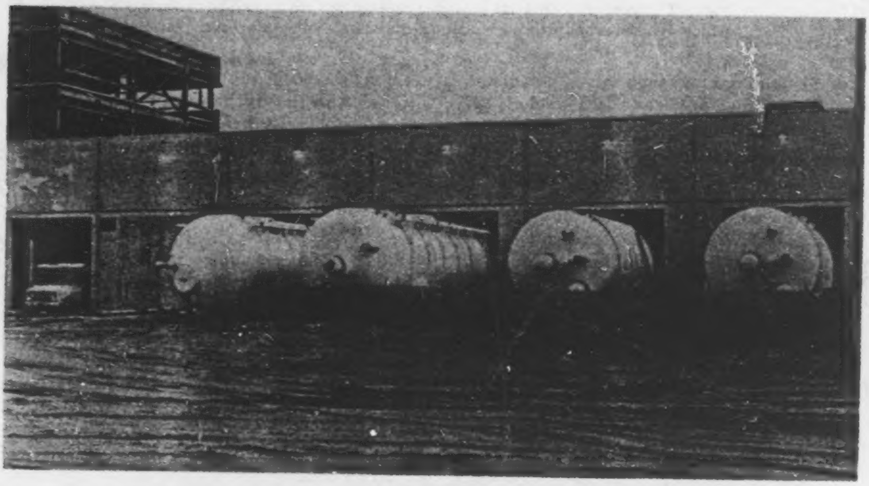

Figure 10. The CBA refrigeration building with cold boxes in the foreground; the service building is under construction behind and to the left.

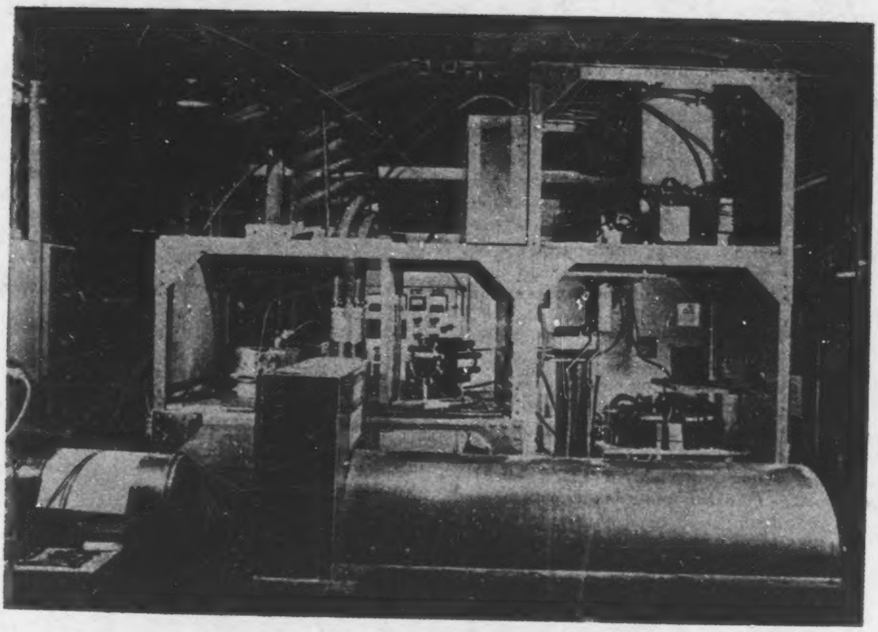

Figure 11. A model of the ferrite loaded accelerating cavity and IB driver, which was successfully tested with more than 12 kV across the cavity gap.

with a single titanium sublimation pump, and b) in the pumpout and leak check of a half cell containing three dipoles and a quadrupole and associated vacuum components which reached 10^{-7} Torr. The recent cooldown and test of the eight full-cell magnets in the CBA tunnel reconfirmed the adequacy of the vacuum system design. Cooldown was started after two days of pumping when the pressure dropped into the low 10^{-4} Torr range. The ultrahigh-vacuum systems again reached 10^{-11} Torr without difficulty and the insulating vacuum again exceeded specifications. The heat load from the bore tube to the magnets was found to be less than 1.3 W per dipole, well below the allowed 2 W.

Injection, Cryogenics, and Controls

Basic design is complete in these areas, with components on order or under construction.

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A.C. Muller (DEE)
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K. Robins
R. Rosenka
W. Sampson
W. Schneider
M. Shapiro
J. Skaritka
A. Stevens
C. Sylvester
P. Thompson
D. Tuttle
P. Wanderer
T. Wild
E. Willen
M. Woodle

ACCELERATOR PHYSICS AND CONTROLS DIVISION

This Division is responsible for the development of the accelerator physics concepts, and the design and construction of control systems and power supplies.

M.Q. Barton, Head

M. Cornacchia
E. Courant
G.F. Dell
R. Edwards
R. Frankel
K. Jellett
S. Kennell
G. Parzen
J. Poole*
B. Pope
J. Wang
R. Warkentein

INJECTION/EJECTION SYSTEMS DIVISION

This Division is responsible for the design and construction of the injection system from the AGS to CBA, and for the design and construction of the beam ejection systems.

H.W.J. Foelsche, Head

J. Claus
E. Jablonski
J. Keane
P. Montemurro
R. Nawrocky
E. Rodgers
R. Thern
J. Tuozzolo
W. Weng
P. Zuhoski

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* On Leave.

CRYOGENICS SYSTEMS DIVISION

This Division is responsible for the design and installation of the helium refrigeration system required for the superconducting magnets.

R.I. Louttit, Head
D.P. Brown, Deputy

Y. Farah
A. Schlafke
J. Sondericker
K. Wu

VACUUM/RF AND BEAM INSTRUMENTATION SYSTEMS DIVISION

This Division is responsible for the design and construction of all vacuum systems, rf stacking and acceleration systems, and beam instrumentation.

H.J. Halama, Head

T. Chou
C. Foerster
S. Giordano
K. Hillman
H. Hseuh
M. Plotkin
M. Puglisi
E. Raka
P. Stattel

ADMINISTRATION DIVISION

This Division is responsible for all administrative activities associated with budgets, contracts, management systems, quality assurance, conventional construction, safety, and experimental facilities.

J.R. Sanford, Head
J. Spiro, Deputy

J. Becker
E. Dale
E. Dexter
J. Feldman
V. Gutierrez
J. King
H. McChesney
P. Mohn
M. Schaeffer
M. Shear
F. Thornhill
L. Turf
D.H. White

BROOKHAVEN NATIONAL LABORATORY MONTHLY REPORT

October 1983

HIGH ENERGY PHYSICS

AGS OPERATIONS

Accelerator Hours for Physics			
Particle Physics	228		
Machine Physics	57		
Total Physics Beam Hours		285	
Non-physics Hours			
Scheduled Downtime	52		
Unscheduled Downtime	225		
Total Nonphysics Hours		277	
TOTAL MANNED HOURS			562
Scheduled Shutdown	86		
TOTAL UNMANNED HOURS			86
TOTAL HOURS IN PERIOD			648[1]
Operating Efficiency*	56%		
Total Accelerated Protons	64.02×10^{17}		
Average Protons Per Accelerated Pulse	0.87×10^{13}		

EXPERIMENTAL OPERATIONS

Beam Line	Exp. No.	Group	Hours Charged
U	734	BNL/Columbia/Illinois/Johns Hopkins/NRL	213
D4	745	Columbia/CERN/BNL	31

Research Beam Hours - Particle Physics	—
- Nuclear Chemistry	—
Total Hours Charged to Approved Experiments	244
Total Number of Approved Experiments Charged Time	2

$$\text{*Operating Efficiency} = \frac{\text{Total Physics Beam Hours}}{\text{Total Physics Beam Hours + Unscheduled Downtime}}$$

[1] 24 hours less this month due to change in reporting period.

EXPERIMENTAL AREAS OPERATIONS AND DEVELOPMENT

The October reporting period was notable for the greatly improved reliability and increased proton intensity delivered to the neutrino area for Exp. 734 (BNL/Penn/Brown/KEK/Tokyo/Osaka/Stony Brook) following repair of the cooling water leak that developed in the first neutrino horn near the end of September. The repair required two weeks of downtime, the first week of which was for cooldown which, with careful planning of the repair, kept the total radiation exposure below five man-rem, half the initial estimate. Exp. 734, which is studying antineutrino-electron elastic scattering, logged more than two hundred fifty hours of running in the last two weeks of the period despite interruptions for maintenance and machine studies in preparation for the acceleration of polarized protons in the AGS. Intensity averaged close to 11 x 10^{12} protons per pulse during the last week of the period. Unfortunately, it was necessary to reduce the AGS repetition period to 1.4 seconds until problems with the rf system could be solved.

Running Exp. 745 (Columbia/CERN/BNL) in the single bunch extraction mode (SBE) became routine with essentially lossless operation. Another run of several days duration should provide Exp. 745 with sufficient information to optimize the design of the target vessel in which muonic helium is to be formed with the stopping muon beam so that the vacuum polarization can be determined from a measurement of the $3d \rightarrow 3p$ muonic transition induced with a CO_2 laser.

The construction effort continued to be dominated by Exp. 776 (BNL/Columbia/Illinois/Johns Hopkins/NRC), the long base line neutrino oscillation search. Work continued on preparation of the 15000 Amp toroid power supply, the third experimental trailer was installed, concrete pads were poured for transformers and the first detector module, consisting of one plane of scintillator and one of proportional drift tubes, was surveyed in place. Design work focused on the narrow band horn mounting and transport apparatus. Minimizing radiation exposure during repairs has been given high priority in the design.

The Experimental Areas Group continued maintenance, rehosing and flushing magnets for the upcoming Slowly Extracted Beam (SEB) run, building up an inventory of spare magnet power supplies, and providing a second experimental trailer for the B1 Test Beam. The "run and test" of all magnets connected to rectifiers in the recently rebuilt power supply house was completed, and the vacuum system and roof were replaced at the "B" Target Station, completing the radiation hardening and modernization of the area. The "B" line instrumentation station was rewired and is being tested. The cooling water system in the "C" area was rebuilt to provide greater flexibility in routing available water, water cooled bus was run and the roof opened prior to installation of an 18 D 36 magnet which was prepared for the C1 line in order to raise its momentum range to 24 GeV/c for Exp. 785 (BNL/Minn/SE Mass), a measurement of the single spin asymmetry in inclusive processes to ninety degrees in the center of mass system.

Modifications to the target stand of Exp. 755 (BNL/Minn/SE Mass), a study of two body exclusive processes at 90° in the center of mass, were completed permitting the rotation of detectors about the beam axis. The liquid deuterium target of Exp. 773 (Brandeis/BNL/Houston/CMU/MIT/New Mexico/Vassar), a search for strange dibaryons in the hypernuclear spectrometer was completed and the target stand is under construction. The liquid helium target assembled by Exp. 774 (Houston/BNL/New Mexico/Vassar) arrived and was found to have several vacuum leaks. They are being repaired and the fill system is being modified. A liquid hydrogen refrigerator was assembled and is awaiting its control system prior to testing. The use of refrigerators should pay for itself in a few years due to reduced gas purchases as well as removing large amounts of flammable material from the experimental buildings.

The SEB instrumentation stations were turned on and are being checked out and calibrated. Parts for four new SWICS were made and the SWICS are being assembled. The four microprocessor SWIC controllers were built and the first unit is being tested.

Drift chamber repair and construction continued at the Multiparticle spectrometer (MPS). Design and production of electronics for the trigger

PWC system has started. Design of the FASTBUS-VAX 11-750 data handler hardware and software continued. Wiring and electronics necessary to connect the VAX in Building 510 to Gandalf and the BNL network were completed. The VAX has been heavily used with 14 days of CPU time consumed in the period and Exp. 734 continued running on-line on the KL10. Additional BNL memory modules were assembled in order to expand the KL10 memory from 512 to 1 Kilowords.

ACCELERATOR OPERATIONS AND DEVELOPMENT PROGRAM

The AGS was scheduled to run FEB for Exp. 734 in the North Area this month. Also scheduled was some running for Exp. 745 using Single Bunch Extraction (SBE) to the D target. After three weeks of problems the intensity came up well with continuous operation reaching previous peaks and the last week averaging greater than 10^{13} proton/pulse. Concern with failures of the RF system required returning to a slower rate of energy gain and repetition period until corrections are made. Problems with high intensity SBE operation have been cleaned up and it is now operationally compatible with full intensity FEB operation.

The first half of the initial three weeks of the month was used to repair the water leak on the horn and to run SBE for studies and Exp. 745. Other studies relating to the polarized proton project were also made. There were failures of two H10 ejector magnets in the following week and a half with four days of running for Exp. 734 between failures. The record for the last week was improved with only two days lost to miscellaneous problems.

AGS Studies

Fifty-seven hours of machine time were taken for studies this month. Essentially all of this occurred while the HEP program was halted awaiting the neutrino horn repairs. Two long shifts were spent working on the single bunch extraction (SBE) mode of operation with effort given to improving extraction and transport efficiencies—both with reasonable success.

One ten hour shift was devoted to ring RF pulsing. This involved testing the RF system in a somewhat reconfigured state which will allow an input to be added in the low level RF system to compensate beam loading in the cavities at injection time.

The remaining 2.5 shifts went toward polarized proton commissioning studies. The 200 MeV polarimeter located just down stream of the linac underwent in-place testing, permitting final design evaluation and revisions. In preparation for the use of another polarimeter, this one located at the G10 straight section within the AGS ring, the main ring magnet power supply was adjusted to permit a short (100 ms) flat period to be inserted in the magnet current program at any point during the cycle. Polarization measurements will ultimately be made during the resulting interval of nearly fixed energy, allowing the polarization at that energy to be determined more rapidly.

Linear Accelerator

The linac operated satisfactorily during this reporting period. Operations were limited because of unscheduled AGS downtime and a water leak at the BLIP target window. A major block of linac downtime (approximately 11 hours) occurred when a 7835 power amplifier hose sprung a leak, dripping water to the floor below causing a fire in the pulsed quadrupole system for the second linac cavity.

After ion source repair and maintenance, Preinjector #1 was brought back into service during this period and performed very well. Negligible amounts of Freon 113 were found via mass spectrometer analysis after startup, and source performance is much more stable than before it was serviced. During the middle of the month the polarities of the two source Septier quads were reversed, resulting in increased beam current.

AGS Computer

Software

System changes were made to permit the Relway gateway to be connected to System-C. The operator interface program AGAST was changed to utilize database resident readbacks (to be used for polarized proton control). The IPM microprocessor program was changed to permit up to 30 triggers per AGS cycle, to utilize faster and bipolar digital-to-analog converters, and to support triggers as close together as the hardware will allow. Other programs receiving maintenance included COSMO (slow multipole parametric control), NC (charting program for ion sources), BRDIS (plotting program for function digitizers), and NORB (orbit plotting).

Hardware

The two recently purchased MG10 memory units (256 K words total) were moved up from Building 940, configured for KA10 processor operation, and installed on System-D for testing. They were quickly commissioned, and immediately used for backup-mode operation due to another failure of System-C memory. When an AGS maintenance period permitted, the MG10 memory was installed on System-C, and the troublesome ARM10L memory moved from System-C to System-D.

The old System-D memory was retired to storage, save for one cabinet (the only trouble-free unit of the previous five units) which was retained in the computer room for spacing purposes. Continued failures and diagnosis of the ARM10L memory have resulted in the identification of three bad boards, which have been returned to Ampex for repair. An RPOP disk drive failed with a bad head-assembly bearing, and was removed from service on System-C. The power supply on the System-D Versatek printer/plotter failed once again; it is hoped that a local revision of the capacitor filter assembly, now under test will permanently solve the problem. The System-C Versatek also failed and was repaired.

AGS Mechanical Engineering Group

F10 Septum Magnet

Magnetic tests of the slab type magnet have confirmed the suspicion of excessively high fringe field. It was decided that the slab type magnet should be replaced with the laminated one before the SEB run. A spare "warm" laminated magnet was fixed and vacuum checked. The magnet was hi-potted and it is ready now for power testing.

Efforts continued to assemble a "cold" magnet. Some parts have to be fabricated yet.

H10 Septum Magnet

The core cooled H10 Septum Magnet failed in operation. The downstream end of the dry septum broke across. It is suspected that fatigue at elevated temperature caused the break. The break was welded up and reinforced with a copper plate. This magnet was reinstalled after the spare water-cooled Septum developed water leaks. The repaired "dry" septum magnet was still operational after eight days of pulsing.

SEC

The unit assembled in Argon atmosphere was baked at 300°C for three days. Aluminum windows annealed and developed a permanent hemispherical set. The unit was disassembled and the window was cut for tensile tests. The samples of window foil will be heated at different temperatures and duration, and tested to determine optimum combination of temperature and time.

Horn

A water leak developed at a stainless steel fitting in the spray cooling water line. A crimping attempt failed; stainless steel tubing broke at the fitting completely. The tubing was replaced and the horn was put back in service.

AGS Electrical Group

An extensive R&D effort was undertaken to understand some of the "tuning" problems associated with the AGS radio-frequency system. Low-pass filters were installed in the rf input signals to the oven amplifiers located in the upper sleeve boxes. This enabled the rf accelerating gap volts to be free from high frequency "noise." New rf crowbar protection was designed to give a higher level of protection to each of the ten systems rather than that which is presently acting only on the common drive signal.

A test set-up was developed in the Main Magnet (Siemens) Power Supply area to enable better and faster re-alignment of the rectifier trigger pulses. Also, operator training was undertaken in servicing many p.c. cards in this area, especially since in some of the equipment failures due to age are being experienced. Some of the p.c. cards were re-designed with the aim of improving the above situation as well as replacing some of the out-dated German components which are no longer available and which have been superceded by more modern and improved versions.

The gauss clock was modified to produce a second pulse which permits the slow $\dot{B}$ porch. This modification was tested. In addition, p.c. cards have been produced which will replace hand-wired versions in some of the slots.

The systems for pulsing the high-field quadrupoles and sextupoles through the SCR bridges were completed and await testing. The circuits have been constructed in such a way as to enable servicing of the filters used during the normal SEB program.

The E5 and H5 fast kickers operated successfully at their normal operating conditions for the SBE and FEB, respectively.

Construction on the horizontal low-field dipoles, located in the rf building, progressed on quick-switchover to the interfacing of the new control system. The control system based on the original scheme for the vertical dipoles used in the polarized proton project was being reviewed at this time.

BROOKHAVEN NATIONAL LABORATORY MONTHLY REPORT

November 1983

HIGH ENERGY PHYSICS

AGS OPERATIONS

Accelerator Hours for Physics			
Particle Physics	593		
Machine Physics	43		
Total Physics Beam Hours		636	
Non-physics Hours			
Scheduled Downtime	48		
Unscheduled Downtime	156		
Total Nonphysics Hours		204	
TOTAL MANNED HOURS			840
Scheduled Shutdown	0		
TOTAL UNMANNED HOURS			0
TOTAL HOURS IN PERIOD			840
Operating Efficiency*	80%		
Total Accelerated Protons	189.49×10^{17}		
Average Protons Per Accelerated Pulse	1.18×10^{13}		

EXPERIMENTAL OPERATIONS

Beam Line	Exp. No.	Group	Hours Charged
U	734	BNL/Penn/Brown/KEK/TYokyo/Osaka/Stony Brook	588
D4	745	Columbia/CERN/BNL	224

Research Beam Hours - Particle Physics	—
- Nuclear Chemistry	—
Total Hours Charged to Approved Experiments	812
Total Number of Approved Experiments Charged Time	2

$$^{*}\text{Operating Efficiency} = \frac{\text{Total Physics Beam Hours}}{\text{Total Physics Beam Hours} + \text{Unscheduled Downtime}}$$

EXPERIMENTAL AREAS OPERATIONS AND DEVELOPMENT

AGS performance continued to improve with new intensity records set and an average of over one hundred twenty hours per week of running time for Exp. 734 (BNL/Penn/Brown/KEK/Tokyo/Osaka/Stony Brook) which took data on antineutrino electron elastic scattering. The previous intensity record of 12.6×10^{12} protons per pulse was raised to 16.0×10^{12} per pulse with a total of 1.9×10^{19} protons accelerated for the reporting period. The anticipated number of antineutrino elastic scattering events accumulated in this run is nearly equal to the number of neutrino events obtained in previous runs and the goal of one hundred of each type of event should be reached early in the next month.

Experiment 745 (Columbia/CERN/BNL), a measurement of the vacuum polarization in muonic helium, ran successfully in the single bunch extraction mode (SBE) receiving one of the twelve circulating proton bunches from the AGS prior to extraction of the remaining eleven to the North Area for Exp. 734. In addition to optimizing the muon stopping rate and further reducing background, Exp. 745 was able to detect X-rays from the air, the degrader and from helium following a muon stopping in the material. An optimized target was designed and fabricated for testing during the next run.

A large construction effort continued in order to prepare Exp. 776 (BNL/Columbia/Illinois/Johns Hopkins/NRL), the neutrino oscillation experiment, for running with part of their detector before the neutrino run ends next month. Chamber installation and survey was begun, the experimental trailers were powered and timing signals from the Main Control Room and from the muon counters in the beam dump are being patched out to the experiment. Work on the toroid coils continued and the manifolds and hosing for water cooling the 15 kA power supply were installed. The 3 collimators for the narrow band neutrino horn with which the experiment will run next Fall were assembled.

An 18D36 dipole magnet was rebuilt and installed in the C1 line allowing the beam to reach 24 GeV/c so that polarized protons of this momentum could be transported to Exp. 785 (BNL/Minnesota/S.E. Massachusetts), a measurement of asymmetries in inclusive two body reactions with polarized protons. Water cooled bus was installed for the magnet and the necessary shielding modification completed.

The run and testing of magnets in the Slowly Extracted Beam (SEB) area continued in preparation for the startup of the physics program in this area in January. A new cooling tower was installed replacing the old Cooling Tower #2 providing cooling water for C line beams and experiments. Maintenance of power supply breakers continued.

A liquid nitrogen cooling system for the Ge solid state detectors of Exp. 781 (BNL/MIT/CMU/Houston/NYU/Vassar), a study of the spin dependence of the Λ-nucleus interaction involving the measurement of hypernuclear gamma rays, is under construction and the liquid deuterium target for Exp. 773 (Brandeis/BNL/Houston/CMU/MIT/New Mexico/Vassar), a search for strangeness -1 dibaryons, was assembled and successfully tested. Repair of a number of vacuum leaks in the liquid helium dewar assembled by Exp. 774 (Houston/BNL/New Mexico/Vassar), for their search for Σ-He^4 hypernuclei was completed. Preparation for the upcoming SEB run started at the Multiparticle Spectrometer (MPS) where checkout of the readout electronics commenced following completion of repairs to the drift chambers. Both the PWCs and drift chambers were reconfigured to optimize the acceptance for Exp. 751 (Brandeis/Duke/Notre Dame/S.E. Masschusetts) which is studying hyperon radiative decays.

Checkout of the SEB instrumentation continued and three new segmented wire ionization chambers (SWIC) were assembled and tested. Work continues on microprocessor based SWIC control units. Conditioning of electrostatic beam separators commenced.

The On-Line Data Facility (OLDF) VAX was heavily utilized with 86 users logging a total of more than 21 days of CPU time. Experiment 734 continued using system B for on-line analysis, logging more than one day of CPU usage. The operating system on both VAXs was upgraded to version 3.4 with only minor problems. A revised OLDF Upgrade Implementation Plan was submitted to DOE for approval and work continued on the VAX 750 based Data Acquisition System during this reporting period.

ACCELERATOR OPERATIONS AND DEVELOPMENT PROGRAM

The AGS ran the full five-week "month" of November for experiments in the North Area. There was a startling increase in intensity this month. The added intensity was particularly useful to the ν experiment. Reliability also improved during scheduled operation.

The intensity improvements over last month were dramatic, with average beam up 36% and peak beam up 25%. This increase was a steady week-by-week growth due primarily to debugging of the source and rf systems and the addition of beam loading compensation for the rf system. Also, improvement of reliability allowed more continuous tuning.

The downtime this month of less than one quarter of scheduled time is a major improvement over last summer's lack of reliability. There still exists the persistent day per week of miscellaneous failures. Only one major failure occurred this month; the ferrite of the H5 kicker fractured as the E5 one did last summer, and had to be replaced.

AGS Studies

Forty-three hours of studies time were taken during the November reporting period. Thirty-six of these hours went to testing systems and techniques needed for polarized proton acceleration. This time was evenly divided between a successful effort to extract and transport a low intensity (1×10^{12}) 6 GeV beam down the D line and a continuation of very low intensity (1×10^{10} protons accelerated, 10-100 microamps in the Linac) studies. The acceleration of the latter very low intensities is now fairly routine; these studies concentrated on efforts to understand and bring into operation the 200 MeV polarimeter, the internal polarimeter, and the low intensity vertical position-measuring electronics.

The remaining studies time, nearly seven hours, was spent setting up, in a semi-permanent configuration, the injection beam current compensation electronics for the ring rf. This was essentially a repeat of work done during September and October, with slightly improved electronics. The system performed quite satisfactorily and is now operational.

Linear Accelerator

This was a good running period for the Linac. Machine reliability was good and peak beam current out of Tank 9 was typically 30 mA. This enabled the AGS to have more than enough protons to achieve record intensities. In addition, the BLIP facility has received its highest average current since the changeover to H^- acceleration. Beam pulse widths for BLIP are approximately 500 μs.

The major contributor to downtime for this month was the rf system; two 7835 cavity failures were the most significant interruption.

Construction on the power source for the RFQ (radiofrequency quadrupole) was completed and it is now in final test. The rf power supply for the third buncher needed for polarized proton acceleration was fabricated and tested.

AGS Computer

Software

The CAOS system was modified to support control of the microprocessor-based devices used in the front end for polarized protons (polarized source, LEBT-II, RFQ). Changes were made to the ring watchdog JEFF to alarm on error conditions in the ring rf system and for Pit I devices (as well as Pit II). The programs responsible for the weekly/annual summary reports and for the daily log were modified to handle the recent dramatic improvement in beam intensity, and to maintain statistics on post-transition intensity (as well as pre-transition). The engineering test program for the polarized proton pulsed quadrupole system was upgraded to include control of the timing system for the pulsed quads; all required systems are now included in the program. Other programs worked on include BRDIS (Datacon buffered ADC display), EAGAL (EAG alarm program), and ENERGY (log program for energy consumption).

Hardware

A System-C failure over the Thanksgiving weekend required four days of backup system operation. Bad switches were discovered in the System-C console and repaired. Two TEC's (operators' interactive fast display) also failed and were repaired. The PPC PDP-8 failed and was replaced by the spare PPD. Diagnostics were unable to re-produce the failure offline. An additional memory card failed in the System-D ARM10L memory. Since we consumed our spare cards in the recent spate of failures, System-D will operate with 32 Kwords offline until repaired cards are returned from the vendor. The System-C Versatek printer/plotter failed and the System-D unit was cannibalized to repair it.

AGS Mechanical Group

F10 Septum Magnet

The laminated septum magnet was pulsed in air. The septum coil was strengthened prior to this test.

H10 Septum Magnet

A spare radiation-warm magnet with the water cooled septum was pulsed on day shifts. A CBA injection line power supply was installed in Building 914 to pulse this magnet.

SEC

One secondary emission chamber unit was assembled in an argon atmosphere, baked at 250°C for two days, and successfully glow discharged. The unit was installed in the U line just in front of the gate to the horn cave.

Shielding Block Lug

Metallurgical examination of the failed lug indicates "brittle" fracture as the cause of failure.

H5 Ferrite Kicker

Both ferrite blocks of the upstream magnet cracked and smaller fragments were lodged in the magnet gap. The upper ferrite block cracked in the same manner as the E5 block a few months earlier.

Polarized Proton RFQ Project

Specification of RFQ end-caps was completed and the drawings were quickly made and released for fabrication. Work was started on the motorized tuners and drawings are almost ready to be released for fabrication.

H20 Electrostatic Septum

About 240 broken tungsten-rhenium wires were replaced. The septum core was assembled in the vacuum vessel and checked for vacuum leaks.

Ionization Profile Monitor

Two spare units were assembled. One unit requires resistors which are on order.

G10 Polarimeter

A moveable filament polarimeter was installed and tested with encouraging results.

AGS Electrical Group

A phase compensation scheme which is active during the AGS injection period was installed and used on an operational basis. This permitted better tuning of the rf system which resulted in higher beam intenstiy. A crowbar protection circuit which decreases the rf cavity gap volts to a safe 3 kV value whenever the voltage exceeds 9 kV on any rf cavity was fabricated and installed.

The electrical extraction equipment for the FEB operated successfully during this period. After the replacement of the E5 kicker, the extraction equipment for the SBE operated successfully for a test run of Experiment 745.

On the main magnet (Siemens) power supply, work continued on the rectifier trigger p.c. card test setup. This will result in improved re-alignment of slopes on the integration-comparator circuits. Work began on checkout of the SEB flat top controls in preparation for the upcoming SEB program. Multiple flat tops at 4 GeV and 6 GeV energies were set up successfully for polarized proton studies. Problems were corrected in the $\dot{B}$ servo loop, in the rectifier control program that takes the magnet voltage from rectify to invert and in the "ring-off" at the end of the invert cycle that resulted in an increase of the "dwell" time.

The first of the AGS high field polarized proton quadrupole systems was pulsed successfully through the SCR bridges. Tests and debugging commenced on the other quadrupole and sextupole systems.

In the vacuum area, design and layout of the vacuum control system for the gas jet experiment (Experiment 778) was begun. This includes interlocking and control of two vacuum valves around the boxes to be installed for the gas jet in the G-20 straight section of the AGS. The interlocking will be accomplished via sensing of the vacuum over a wide range of pressures rather than the regular interlocking at a fixed pressure of 2 x 10^{-5} Torr.

BROOKHAVEN NATIONAL LABORATORY MONTHLY REPORT

December 1983

HIGH ENERGY PHYSICS

AGS OPERATIONS

Accelerator Hours for Physics			
Particle Physics	373		
Machine Physics	56		
Total Physics Beam Hours		429	
Non-physics Hours			
Scheduled Downtime	46		
Unscheduled Downtime	78		
Total Nonphysics Hours		124	
TOTAL MANNED HOURS			553
Scheduled Shutdown	119		
TOTAL UNMANNED HOURS			119
TOTAL HOURS IN PERIOD			672
Operating Efficiency*	85%		
Total Accelerated Protons	132.33×10^{17}		
Average Protons Per Accelerated Pulse	1.28×10^{13}		

EXPERIMENTAL OPERATIONS

Beam Line	Exp. No.	Group	Hours Charged
U	734	BNL/Penn/Brown/KEK/Tokyo/Osaka/Stony Brook	366
U	776	BNL/Columbia/Illinois/J.Hopkins/RRL	57
U	779	BNL	1

Research Beam Hours - Particle Physics	423
- Nuclear Chemistry	1
Total Hours Charged to Approved Experiments	424
Total Number of Approved Experiments Charged Time	3

$$\text{*Operating Efficiency} = \frac{\text{Total Physics Beam Hours}}{\text{Total Physics Beam Hours} + \text{Unscheduled Downtime}}$$

EXPERIMENTAL AREAS OPERATIONS AND DEVELOPMENT

New AGS intensity records were again set in the December period with a peak of 16.2×10^{12} protons per pulse and 12.8×10^{12} protons per pulse average over the reporting period. Experiment 734 (BNL/Penn/Brown/KEK/Tokyo/Osaka/Stony Brook) finished their measurements of neutrino and antineutrino electron elastic scattering, having switched back to neutrino scattering after obtaining the desired number of antineutrino events. Experiment 745 (Columbia/CERN/BNL), which is to measure the vacuum polarization in muonic helium, was unable to run due to the second failure of the ferrite kicker magnet that initiates single bunch extraction (SBE) in which one of the twelve circulating proton bunches in the AGS is extracted into the East Experimental Area for Exp. 745, with the remaining eleven bunches going to the North Area for neutrino physics.

Experiment 776 (BNL/Columbia/Illinois/Johns Hopkins/NRL), the neutrino oscillation search, which is to run next fall with a new narrow band neutrino horn, was able to activate the part of their detector that is installed (approximately 30 tons) during the last few days of the run and obtained neutrino event candidates as well as beam related muons. The neutrino run ended on December 20, for the winter shutdown.

Construction of Exp. 776, which went on throughout the period, included power and water cooled bus runs to the power supply house where construction of the 15 kA toroid power supply was completed enabling the run and test of the toroids to begin. A method of accurately surveying proportional tube detector planes was devised and a survey tower was fabricated and installed. Temporary timing signals were run overland to Exp. 776, 1 km beyond the neutrino horn for this run while a permanent cable run was being installed.

The 18D36 dipole magnet installed in the C1 beam, in order to raise its momentum limit to 24 GeV/c so that polarized protons of this momentum can be transported to Exp. 785 (BNL/Minn/SE Mass) which is to measure asymmetries on two body inclusive production, was run and tested and the roof replaced.

The carbon regenerator and 18D72 dipole magnet in Exp. 749 (Yale/BNL), a measurement of milliweak CP violation in $K_L - K_s$ decays, were repositioned in order to improve the experimental acceptance. Preparation began for the installation of the vacuum chamber of Exp. 778 (Purdue), which is to study nuclear fragments produced in proton-nucleus collisions with a gas jet target in the AGS ring vacuum.

Following vacuum testing of the vacuum box for the spare 10C20 septum magnet for LESB I, to replace one which had suffered coil damage during the run and test, the roof over the existing magnet was removed and the magnet disconnected prior to replacement with the spare which had recently been rebuilt.

Run and test of all magnets for the upcoming Slowly Extracted Beam (SEB) run in January continued. All adjustable collimators in beam lines were checked out. The cluster system for emergency magnet shutdown which had recently been remoted to the Main Control Room was successfully tested. Vacuum "O" rings and hoses in the switchyard and in the external proton beams were replaced with new ones. Conditioning of the beam separator began. Testing of the newly designed Secondary Emission Chamber (SEC) in the U line was successfully concluded. An increase of only 5% in sensitivity was observed for a total integrated proton flux of $10^{19}/cm^2$. Three new Segmented Wire Ionization Chambers (SWIC) were installed in the "A" line and check out of all beam instrumentation stations was completed. The prototype microprocessor based SWIC controller was completed.

All hydrogen targets on the experimental floor were checked out and appear to be in good operating condition for the SEB run. The liquid nitrogen fill system for the solid state (Ge) gamma ray detector of Exp. 781 (BNL/MIT/CMU/Houston/NYU/Vassar) was completed and successfully tested. The detectors are to be used in the measurement of hypernuclear gamma rays. The helium target system for Exp. 774 (Houston/BNL/N.Mexico/Vassar) is nearing completion. Leaks in the dewar supplied by the experimenters have all been repaired and the heat loss is now approximately equivalent to 1/3 liter of liquid helium per hour which is quite satisfactory. The liquid helium target is to be used in a search for Σ-He^4 hypernucleus production.

The MPS magnet was rotated to a 3° offset from the Medium Energy Separated Beam (MESB) in order to increase the acceptance for Exp. 751 (Brandeis/SE Mass/Notre Dame/Duke) which is to study radiative hyperon decays. All chambers have been rearranged to optimize the experimental acceptance. Checkout of drift chamber electronics is complete and testing of PWC electronics and the data acquisition system is about to begin.

VAX usage at the On-Line Data Facility (OLDF) remained high with 23 days of CPU time used during the period as PDP-10 users continue their migration to the VAX in anticipation of the demise of the PDP-10s next summer. DOE approved the revised OLDF Upgrade Implementation Plan. Design of the VAX 750 based data acquisition system continued and simulation hardware was designed with the intention of testing the system in February.

ACCELERATOR OPERATIONS AND DEVELOPMENT PROGRAM

The AGS ran for three weeks this month to finish Experiment 734 in the North Area. The average and peak intensities continue to increase with a new record of 16 TP accelerated. The monthly average beam to the FEB target was 12 TP with a 1.4 sec repetition period or about 1.5 μA average. Reliability improved slightly with beam on over 80% of the time. The AGS shut down on December 22 for a three-week maintenance period to prepare the accelerator for SEB operations in late January.

AGS Studies

Fifty-six hours of machine time was devoted to studies during December, twenty-five of these occurring after HEP concluded on December 21. The primary study subjects were associated with polarized proton acceleration. Ongoing commissioning studies of the G-10 internal polarimeter, working at realistic ($2\text{-}4 \times 10^{10}$ circulating protons) intensities, used 16 hours. One shift was spent learning how to extract a 6 GeV beam to the D target. Another shift was spent studying the pulsing of one of the resonance jumping quadrupoles, at seven energies during the acceleration cycle. This exercised the control system and at full AGS intensity had no significant affects on the accelerating beam. The test was repeated at polarized proton intensity while observing beam position with high gain electronics located nearby. Again, no coupling was observed.

In another study effort, five hours of effort to extract a single bunch to the D line, eleven to the U line (SBE mode), met with frustration as the repaired kicker at E5 dropped more chips into the path of the beam.

Half of a shift was devoted to measurements of transverse beam sizes in the FEB line, this to give emittance measurements as input for the design of a replacement for the superconducting magnets in that line.

One shift of injection studies, using a linac pulse less than one AGS circumference in length, documented beam position and other related beam parameters at injection. Four hours were spent in a first look at transverse stopband corrections, noting changes in beam loss as the various correction strings were turned off. In addition, the longitudinal behavior of bunches was documented under various rf voltage programs. Finally, four hours were spent studying the rf main tuning current controls.

Linear Accelerator

The Linac operated very well at the beginning of the month but stumbled a bit toward the end. A coupling at one end of the heat exchanger for the rf cooling water sprang a leak and all Linac water systems, including the cooling tower, had to be shut down until a repair could be effected. All systems were down for about eight hours, but were restarted readily with the exception of the ion source. The highest Linac current available after the water failure was about 19 mA, as opposed to 28 mA previously. HEP lost about 14 hours because of the water outage. During the coming Christmas shutdown the ion source will be cleaned and reconditioned.

AGS Computer

Software

Changes were made in several control system programs to accommodate the presence of Relway-based hardware: the AGS scheduler program SAGS to recognize PPQ (the Relway peripheral processor), the error logger PPERRL to recognize PPQ, THLP to use the PPQ interface in test mode for reloading PDP-8's. The control interface program AGAST was modified to accept a hardware designation that device readbacks are resident in the shared memory data base and are not to be acquired real-time from hardware (this is important for readbacks processed by parametric control programs). An engineering test program for the pulsed dipoles (DIPET) was implemented, and the engineering test program for the pulsed quadrupoles was finished. The pulsed dipole (imperfection resonance) control program was made about 85% complete.

Hardware

The Relway gateway was transferred from the development system System-D to the control system, System C. Major problems developed in the communication link between the gateway LSI-11 and the System-C PDP-10, which were not present when the gateway was connected to System-D. The gateway was reconnected to System-D pending resolution of these problems. The failed RP02 disk drive on System-C was replaced. The System-C line printer developed a bad hammer driver card, which was replaced. The Ampex ARM10L memory on System-D developed another bad memory card. In the absence of spares (all spares have been consumed, bad cards still at vendor for repair), System-D is now running with 32K words of memory offline.

AGS Mechanical Group

E5 - Ferrite Pulsed Magnet

It was decided to temporarily repair the failed magnet and install it in the AGS ring. Cracked fragments of the ferrite were pried out and the cracked parts of the ferrite were clamped with a stainless steel plate. The assembly was pulsed with full operating current for approximately four hours. The magnet was observed through a plexiglass window; it behaved normally. After installation, the magnet was pulsed but the beam could not be extracted. The magnet was removed and three small ferrite fragments were found in the gap.

H5 - Ferrite Pulsed Magnet

This magnet, when it failed in service, was replaced with an E5 magnet after appropriate terminal modifications. It operates satisfactorily so far. Ferrite blocks for two magnets, on order since the end of September, were pressed and fired. The vendor is ready for machining but awaits our instructions on modifications. The following instructions were sent to the vendor on December 22:

a. All eight ferrite blocks will have field shaping tips removed, increasing the effective gap from 0.5" to 0.562".

b. Two upstream holes in the upstream half of the magnet will be removed. Four ferrite blocks will be affected.

The expected delivery is the middle of January, 1984.

SEC

The first SEC unit that was baked out and glow discharged appears to perform satisfactorily in the U line.

G10 Polarimeter

Dovetail slide parts were made of brass and were galling in vacuum. The parts were polished and lubricated with a graphite spray.

Polarized Proton Project

1. LEBT Line. Welds of the cesium trap leaked and had to be re-worked. Most of the equipment is installed in the line.

2. RFQ. End caps were fabricated from copper-clad steel plates. The rolled and welded cylindrical part came out somewhat oval. On clean-up machining, some portions of copper machined out down to steel substrate. These patches will be copper plated.

L15 Pulsed Quadrupole

The quadrupole assembly was taken out of the AGS ring on the suspicion of a vacuum leak. Brown discoloration of the plexiglass covers indicates the areas of radiation damage.

AGS Electrical Group

A final design and prototype construction of the new phase compensation circuit in the AGS accelerating rf system was started. This circuit was successfully operated on a test basis during the latter part of the last running period and led to the new intensity record. The final version will have multiple sections so that beam phase compensation can be applied up to three times during an AGS pulse.

An rf system group was organized to look into further AGS rf system improvements, as well as to design the rf system for AGS heavy ion acceleration.

The fast extracted beam (FEB) equipment operated successfully and reliably during this period for Experiments 734 and 776. Experiment 776, which started near the end of the run, was provided with AGS timing and beam signals at the experimental trailer, so that the experimenters could begin testing their apparatus in sync with the AGS. The single bunch extraction (SBE), used for Experiment 745, had a setback in this period, as described above.

In the SEB area, a newly constructed laminated F10 ejector magnet was successfully tested and is ready to be placed in the machine during the January shutdown, prior to SEB operation. Also, an H20 electrostatic septum is being readied to replace the unit presently in the machine which has many broken wires. Work began on getting the other equipment, required for SEB, ready for operation.

The power supply and SCR bridge system that is used to power the second set of AGS high field ring quadrupoles were tested and produced the necessary bipolar pulses to be used during polarized beam acceleration. In addition, testing commenced for 24 vertical low field dipole power supplies in the E10 house with their associated computer controls. The system operated successfully during this initial testing in its new configuration required for polarized beam operation.

The first fast quadrupole modulator system was completely tested and has undergone all the necessary modifications and is now operational. It was operated via computer control from the MCR during normal beam operation and no deleterious effects were observed on the beam. Two of the low voltage capacitor bank power supplies are undergoing testing at the vendor's plant and will be delivered to BNL by the end of December.

1.2 General Plant Projects (Project No. 85-R-101)

1. Included among the examples of the major items to be performed under General Plant Projects (GPP) at BNL are $300,000 in "building additions for the NSLS" (i.e., the National Synchotron Light Source), and a $350,000 addition "at the NSLS facility to serve as a target room for development of the high-energy gamma-ray beam." Aren't these projects very specific to the NSLS, and if so, why are they not funded by Basic Energy Sciences?

Answer: By DOE Policy, projects such as the building additions for the National Synchrotron Light Source whose estimated cost is under $1 million, are included in the General Plant Project category instead of being treated as separate construction line items. This particular project is not funded by the Basic Energy Sciences program because it is being proposed as a General Plant Project (GPP) and the Department has assigned responsibility for all GPP at Brookhaven National Laboratory to the High Energy Physics Program.

2. BNL's GPP items for FY 1985 include $400,000 in "power improvements to provide an additional 5 MW of power for the installation of new experimental areas at the AGS"; and $550,000 for "a new accumulator tunnel to connect the existing 200 MeV Linac with the former 50 MeV Linac building and house the accumulator equipment." Are either or both of these projects closely tied to the Tandem/ AGS Heavy Ion Transfer Line project (Project No. 84-R-123) in the Nuclear Physics Program? If so, shouldn't these projects be included as part of the cost of Project No. 84-R-123?

Answer: The two General Plant Projects (GPP) for "power improvements" and for "a new accumulator tunnel..." are not related to the Heavy Ion Transfer Line project (84-R-123). The "power improvements" GPP will provide badly needed power for new beamlines in the Alternating Gradient Synchrotron (AGS) experimental areas. The "accumulator tunnel" GPP is related to planned increases in the beam intensity for the AGS polarized proton capability.

3. Please describe the $300,000 GPP for "building alterations and expansion to provide a facility for coal-water slurry technology and cleaning." Will there be research carried out in this facility? If so, who will be sponsoring this research, and why are they not funding this project?

Answer: The General Plant Project (GPP) for building alterations and expansion to provide a facility for coal-water slurry technology and cleaning will provide a wet-chemistry type laboratory and coal preparation room at the Works Area Building and will house research programs in these areas supported by the Fossil Energy Program. As explained above in the response to question 1.2.1, this project fits the requirements for GPP and the Department has assigned responsibility for all GPP at Brookhaven National Laboratory to the high energy physics program.

2.0 Fermi National Accelerator Laboratory (Fermilab)

1. **What have been Fermilab's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: Fermilab physics research highlights from FY 1981 to the present have primarily resulted from studies of the quark constituents of nuclear matter, and the properties of neutrinos and the weak interactions. Incisive results on the distributions of quarks within nucleons have been obtained from experiments using pions, protons, neutrons, photons and neutrinos as probes of nuclear substructure. Particular emphasis has been given to the production mechanisms of charmed quarks, and to measurements of their lifetimes and other properties. High precision determinations of the magnetic moments of heavy particles containing strange quarks have imposed stringent limits on theoretical models of how quarks combine to form these particles. New limits have been set on the possible masses of neutrinos, which imply in turn that the total mass of the universe is sufficiently small that the universe is predicted to continue indefinitely its present state of expansion into space. Studies of the production of high transverse momentum particles in hadronic interactions have established that collimated jets of particles emerge at large angles, providing further support for the quark substructure of nuclear matter. The observation that photons are directly produced in hadronic interactions has yielded further confirmation that nuclear matter contains gluons as well as quarks.

The accelerator technology highlight of the national high energy physics program was achieved last year at Fermilab when the superconducting magnet Energy Saver/Tevatron facility established a new world record of 800 GeV for accelerated and extracted proton beams. The new accelerator is now in routine operation for physics research use.

For the rest of FY 1984 and through FY 1985, about 15 new physics experiments are scheduled to be performed using the Tevatron. These will explore the behavior of a wide variety of fundamental subnuclear processes for the first time at the new very high energies made available by the Tevatron facility. Several neutrino experiments now scheduled will yield information on subnuclear structure with finer detail than ever before possible. Much greater precision measurements on the lifetimes of charmed particles will be made, with the capability of detecting lifetimes as short as about 10^{-15} seconds. A comparison of beam particles in the same experimental apparatus should allow clean separation of the quark and gluon contributions to hadronic scattering processes. A precision measurement of rare decay modes of neutral kaons will try to establish whether or not those processes violate the principle of time reversal invariance.

In accelerator technology, a highlight at Fermilab will be the commissioning of the antiproton source of the Tevatron I project.

2. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: Between FY 1981 and FY 1985, very significant improvements and additions to Fermilab's accelerator and experimental research facilities are being made under the Energy Saver, Tevatron I and Tevatron II construction project. Most prominent is the four mile circumference ring of about 1000 superconducting magnets, and associated cryogenic systems, provided by the Energy Saver project. This has replaced the original conventional magnet 400 GeV acceleration capability accelerator, now operated as an injector at 150 GeV, with facilities to circulate proton beams at up to 800 GeV and to extract beams at up to 500 GeV into the existing external fixed-target experimental areas. The Energy Saver was funded from FY 1979 through FY 1982, at a total plant cost of $50.8 million, and is now fully operational for research.

Starting in FY 1981, with a total of $82.5 million in plant funding scheduled through FY 1986, the Tevatron I project has enhanced the capability of the Energy Saver superconducting accelerator to about 1000 GeV (1 TeV), is adding to the Fermilab complex an intense source of antiprotons and the additional components required to inject antiprotons with the superconducting ring in the opposite direction to protons and accelerate them to about 1000 GeV, and is providing two new colliding beam experimental areas in which antiproton proton interactions will be available for research at the unprecedented reaction energy of 2000 GeV. This project is now about one-half complete, and is scheduled for full completion and initial research utilization by the end of FY 1986. Major new detector facilities for this colliding beam research are being fabricated with capital equipment funds.

In order to fully exploit the new 1000 GeV beam capabilities provided by the Energy Saver and Tevatron I project, extensive upgrades of the existing external fixed-target experimental areas and five new secondary beam facilities are being accomplished under the Tevatron II project which will cost $49.0 million in total from FY 1982 through FY 1985. Most of the facility upgrades have already become operational for research, and the new secondary beams and experimental halls will be operational by the end of FY 1985. These new experimental capabilities are a high intensity muon beam, a polarized proton beam, a broad band photon beam, a prompt neutrino beam and a high intensity pion beam. New experiments in all of these have been approved and are now being fabricated for first research operations by late FY 1985, using capital equipment funds. The Tevatron II project has also provided improved materials handling capabilities at Fermilab in the form of a large new industrial building used for the fabrication and assembly of technical components and experimental detectors.

A diversity of smaller but programmatically important changes and additions to the Fermilab accelerator facilities have been and will continue to be made on an annual basis as Accelerator Improvement projects, and corresponding plant improvements and enhancements are supported as General Plant Projects.

3. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to Fermilab. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: Funding profiles for Fermilab from FY 1981 through FY 1985 are given in the table below. These funds are all provided by the DOE high energy physics program, with the sole exception of the In-House Energy Management funds provided under DOE Departmental Administration. The sums shown are actuals for FY 1981 through FY 1983 and estimates for FY 1984 and FY 1985. The physics research activity of Fermilab staff is all in-house research; no out-of-house research is performed by Fermilab staff. The Fermilab research staff does devote a fraction of their time to activities activities which assist the research of programs of outside users at Fermilab.

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$79,132	$88,542	$107,874	$113,157	$124,700
In-House Research	5,999	6,252	8,542	9,407	10,000
Operations	50,153	59,150	68,300	75,100	88,700
Other Operating Expenses	22,980	23,140	31,032	28,650	26,000
Capital Equipment	17,000	18,450	23,600	26,250	32,100
Plant	24,900	33,540	43,860	41,500	41,600
Energy Saver	17,300	6,500	--	--	--
Tevatron I	2,000	14,100	18,000	20,000	21,300
Tevatron II	--	6,000	18,000	13,000	12,000
Accel. Improv.	3,400	3,900	4,500	5,100	5,300
General Plant	1,400	1,840	2,460	2,500	3,000
In-House Energy Management	800	1,200	900	900	--
Total DOE Funding	$121,032	$140,532	$175,334	$180,907	$198,400

4. How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: Fermilab is a single purpose national laboratory which is solely supported by the DOE high energy physics program for its primary research efforts in high energy physics.

Two other Federal agencies have supplied limited funds for other activities hosted by Fermilab. From FY 1981 through FY 1985, the National Science Foundation is expected to provide a total of about $60,000 for partial support of Summer Schools on Particle Accelerators and of Symposia on Particle Physics and Technology; and the National Aeronautics and Space Administration is expected to provide a total of about $300,000 to support a few astrophysicists as Fermilab staff members.

Fermilab also serves as host to an on-site Neutron Therapy Facility for the treatment of cancer patients. Neutron beams and a small patient irradiation laboratory are made available to the Neutron Therapy Facility on a parasitic, no gain-no loss basis. Fermilab is reimbursed for the incremental costs of providing this service by a grant from the National Cancer Institute, and the reimbursement from FY 1981 through FY 1985 will total about $5 million. The National Science Foundation provides funding to a number of the university user groups which do their experiments at Fermilab.

5. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

   Answer: Actual Fermilab staffing in FY 1981 through FY 1983 was 2055, 2190, and 2290, respectively. The staffing estimates for FY 1984 and FY 1985 are about 2400 and 2500 people respectively.

6. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

   Answer: The actual and estimated utilization of the Fermi National Accelerator Laboratory's proton accelerators--main ring proton synchrotron in FY 1981 and FY 1982; main ring and Energy Saver in FY 1983; and Energy Saver/ Energy Saver/Tevatron starting in FY 1984--is shown in the following table:

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Utilization in weeks of running	21	23	18	34	35

   FY 1983 was a transition year with most of the time being devoted to installation of the Energy Saver. A practical movement utilization of the Energy Saver/Tevatron would normally be about 48 weeks. However, in FY 1985, a shutdown of about four months is needed for construction related to the Tevatron I program in order to permit implementation of antiproton-proton collisions at 1000 GeV per beam in FY 1986. Thus, the projected FY 1985 utilization is essentially full utilization under the particular circumstances of that year.

7. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

   Answer: From FY 1981 through FY 1985, we expect that 44 experiments will have been completed at Fermilab, 32 new experiments will have been started, and 3 of these will continue to operate beyond FY 1985. About 18 more new experiments, scheduled for operation beyond FY 1985, will be in the fabrication and assembly stages during the period in question.

8. **What is Fermilab's user policy?**

   Answer: Fermilab's facilities are available to qualified physicists whose research proposals are judged, after thorough review by the Fermilab Physics Advisory Committee and the Laboratory management, to be of highest scientific promise and compatible with Fermilab's capabilities and resources. Beam time is provided free of charge to the user for approved high energy physics experiments. For each approved experiment, an agreement is negotiated at the time of scheduling by the Laboratory and participants in the experiment specifying the responsibilities, commitments, and contributions of all parties.

9. **For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?**

Answer: The only reimbursable work done at Fermilab is the Neutron Therapy Facility discussed in response to question 2.0.4. Total reimbursement to Fermilab for incremental costs associated with this facility is estimated to be about $5 million over the FY 1981 - FY 1985 period.

10. **What is the mechanism by which specific research proposals for experiments at Fermilab are considered?**

Answer: The Physics Advisory Committee (PAC) advises the Director of Fermilab on the disposition of experimental research proposals. The PAC consists of 12 prominent high energy physicists who are appointed for three year terms on a rotating basis. No more than three members are Fermilab employees. They are selected by the Director after broad consultation within the national high energy physics community. Two of the four new members appointed each year are chosen from a list of candidates submitted by the Executive Committee of the Fermilab Users Organization. The Chairman of the PAC is appointed by the Director.

Each proposal is first studied by a Fermilab staff physicist who prepares an impact statement describing the demands the experiment would put on Laboratory resources and personnel and the amounts of accelerator beam time and intensity which would be required. The proposals and impact statements are mailed to all PAC members in advance of their meetings; usually hold four times per year. The PAC Chairman assigns each proposal to an informal subcommittee of PAC members for particularly close scrutiny.

At each PAC meeting, the proponents are invited to discuss their proposal before the PAC, the Director, and any other interested observers at a public presentation, and to respond verbally to questions anyone may have. The PAC, Laboratory Director, key Fermilab staff members, and observers from the DOE and the National Science Foundation then hold a closed meeting at which each proposal is discussed further. If the PAC desires further information from the proponents or the Laboratory, they draw up a list of questions and defer the proposal.

The recommendations of the PAC are based primarily on the scientific promise and merit of the proposed physics, although consideration must also be given to the competence of the proponents to carry out the experiment, the total demands on Laboratory funds and facilities, the compatibility with other scheduled experiments, and the availability of an appropriate secondary beam line or experimental facility.

11. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

Answer: During the past five years, 130 research proposals were submitted to Fermilab. Forty-seven of them received approval.

12. **How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?**

Answer: During the past five years, about 1050 university-based researchers (faculty and students) have been involved in experiments carried out using Fermilab research facilities or in experiments being prepared for future use of Fermilab facilities.

13. **How many industrial researchers have utilized the facility over the past five years?**

Answer: There have been no physics research proposals to Fermilab from industrial researchers during the past five years.

14. **How many researchers from foreign institutions have utilized the facility over the past five years?**

Answer: During the past five years, about 325 physicists from foreign institutions have been involved with experiments carried out using the Fermilab research facilities or with experiments being prepared for future use of Fermilab facilities.

15. **How many researchers from other agencies have utilized the facility over the past five years?**

Answer: There have been only two or three employees of other Federal agencies who have done high energy physics research at Fermilab, by participating as individuals in collaboration with other scientists; but it is noteworthy that about 170 physicists from U.S. universities whose direct research support comes from the National Science Foundation have used Fermilab facilities for the pursuit of their research projects during the past five years.

16. **What are the future development possibilities for Fermilab (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

Answer: There are many potential future development possibilities for the existing Fermilab accelerator and experimental facilities and those now under construction, but there are currently no specific plans to undertake any of them beyond the construction activities identified in the FY 1985 budget request. A major new accelerator capability, the Energy Saver superconducting synchrotron, has recently become operational at Fermilab. The two construction projects now in progress will significantly upgrade the fixed-target experimental capabilities (Tevatron II) and add an antiproton-proton colliding beam capability (Tevatron I). Thus, by 1986 Fermilab will have a great variety of new and worldwide unique physics research capabilities and will be the workhorse of the U.S. high energy physics program. We intend to give high priority to the exploitation of these unique capabilities. This will require significant allocations of operating funds over a number of years and major investments in capital equipment monies for secondary beam lines and experimental research detectors during the next several years.

New research instruments and experimental devices will be developed as the physics research program progresses over the next ten years or so. They will originate primarily from the best of the experimental research proposals submitted to the Laboratory over the years and will be funded from annual allocations to Fermilab of capital equipment funds.

17. **Please provide a copy of Fermilab's latest annual report.**

Answer: A copy of the Fermilab annual report for 1983 is attached. Also attached are copies of several recent Fermilab monthly status reports.

Fermilab 1983

Annual Report of the Fermi National Accelerator Laboratory

Fermi National Accelerator Laboratory
Batavia, Illinois

Operated by Universities Research Association, Inc.
Under Contract with the United States Department of Energy

I. State of the Laboratory

Initials!

A free association of Fermilab activities generates a fog of letters, usually in the Latin alphabet. These swim, vibrate, float, and occasionally clump together like quarks in the early universe. They form TeV, CDF, SSC, DOE, URA, and just when each grouping begins to convey significance, nonsense arrangements appear: LEP, PEP, YEP, and AEC, BEC, DEC, and O SAY CAN YOU SEE.

TEV,CDF,SSC,DOE,URA,LEP,PEP,YEP,SEE

Steady!

This is a serious annual report. The fifth in the reign of the author. And it behooves us to have an incisive review of 1983 and an inspiring perception of the future. After all, each such annual report has such a review--has a basic theme, has a lesson. It is time to review the reports.

In 1979 we noted that HEP was in a revolutionary state, that Fermilab would have $\bar{p}p$ collisions by 1983, that the Energy Saver was underway and that our funding was too low.

In 1980 we reviewed the state of high-energy physics and how the Tevatron program would impact. We discussed the theoretical desert and the success of the Left Bend. We were concerned with the stability of Saver magnets but tried to describe a Gottingen-on-the-Prairie environment. We wept bitter tears about the funding problems.

In 1981 we were reduced to Shubert Lieder and in particular the one that sang:

> *Beautiful Science! in how*
> *many grey hours*
> *When life's complications*
> *overwhelm me*
> *Have you kindled warm love*
> *with your powers*
> *And charmed me into a*
> *better world.*

We proudly defined the Energy Saver project as "mature." We were cautiously optimistic about a new TeV I design but were alarmed at European pace which, we said, threatened to convert collaborative competition into subservience. And we were strident about our underfunding.

In 1982 we looked forward, sideways, and backward to the end of the "old 400 GeV" machine. It was the tenth anniversary of the experimental program and we also gave fulsome albeit unnecessary praise to the theorists. The Saver had done the "3/4-A sector" test which greatly encouraged all of us. Oh yes, we described a Dedicated Collider and the Desertron was mentioned. We prayed earnestly for more money.

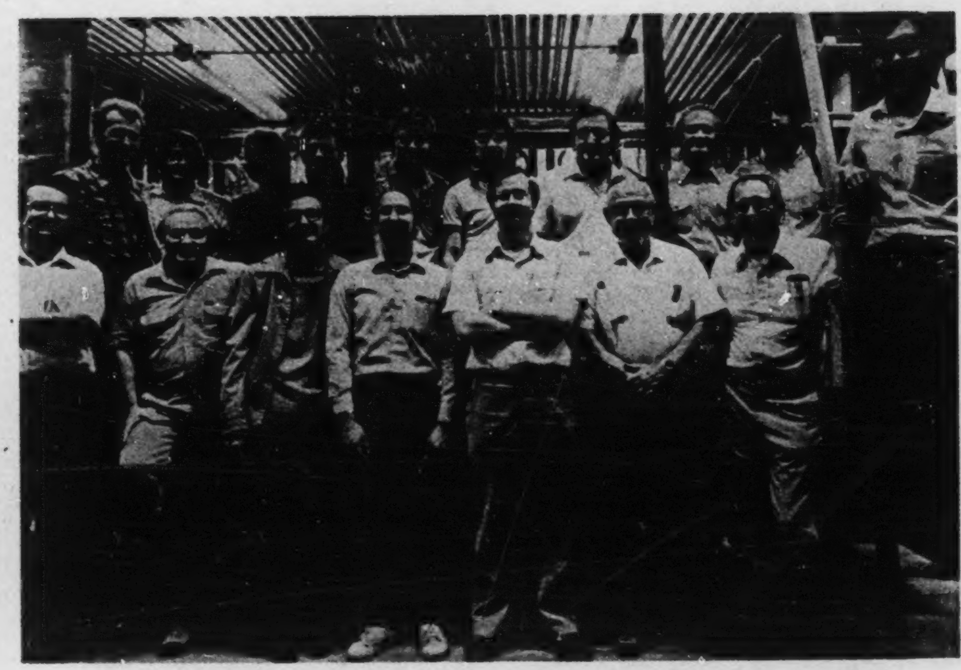
We come to 1983, a year in which our funding prayers were substantially answered. It was also a year made immortal by the operation of the Energy Saver. This is described here in adequate detail by Helen Edwards. Her article will be an important part of the history of our times since it is clear that the successful operation of the Saver has significance for the science that is now being done (TeV II), for the science to be done soon (TeV I) and for the long range future of this subject as it evolves worldwide.

The truly spectacular happening capping the 512-GeV exploit of July 3, its subsequent media blitz, and the spectacular lab-wide party that followed--the really splendid happening was the start of Tevatron physics on October 1, 1983. We started with a partly held-over 400-GeV program--the idea being to learn a lot about the machine before facing the very difficult problems of operation at high intensity close to the domain where the magnets may "quench." This has in fact been very fruitful. The gradually improving efficiency, the achievement of a 15 second spill, the improvement in our control of beam orbitry, the exercise of the new switchyard and cryogenic beam lines--all are historical milestones in the art of accelerators. Studies of the machine have been encouraging for TeV I (storage times in excess of 30 hours) and the SSC (successful deceleration of the injected beam to 60 GeV). The 400-GeV program will terminate early in February and, in a three week shutdown, an important test of the TeV I collider option will be installed: the "low β" quadrupoles in the B0 straight sections will teach us how to run the accelerator in the collider mode. When we resume in March, it should be in the 700-800 GeV range and an entirely new set of problems will be encountered and the results described in the '84 Annual Report.

What we are witnessing is the gradual restoration of Fermilab as an operating laboratory. We have still much to build and we will be building through part of 1986, but there is a revival of spirit that comes from doing physics again--a new-old sweetness of mood. Even the complaints are a joy: "the spill has 60 cycle ripple," "the cafeteria closes too soon," "we desperately need another week..." etc. The physics start is impressive.

E-400, a collaboration of Colorado/Fermilab/Illinois/Milan/Pavia, is a third-generation attempt to capitalize on the enormous production of charmed particles by neutrons. The key here is an active target that will respond to the finite lifetime of the charmed objects. A large effort from Fermilab/Stony Brook/CERN/KEK/Columbia/University of Washington (**E-605**) has begun the study of leptons and hadrons at transverse momenta near the kinematic limit. In the current data taking, they hope to address curious effects observed when very hard collisions take place in nuclear targets.

E-609, an Argonne/Lehigh/Rice/Penn/Argonne/Wisconsin collaboration, is looking at quark-pair emission via identified "jet" pairs. Any doubts about the fact that quarks appear as jets were resolved by the CERN $\bar{p}p$ collider work. This makes the present experiments interesting in new ways. A Chicago/Princeton (**E-615**) group concentrates on the quark-antiquark annihilation process and, in particular, an arcane theoretical prediction that goes to the heart of our current favorite (QCD) strong interaction theory. The highest priority has gone to **E-715** which involves Chicago/Elmhurst/Fermilab/Iowa State/University of Iowa/Yale/Leningrad. This curious mixture has the obligation of settling a baffling dispute between four previous experiments and an unassailable theory of Professor N. Cabibbo which insists that electrons arising from the decay



E 715 IS HONORED AND PROUD TO BE THE FIRST ENERGY SAVER USER

OCTOBER 1, 1983

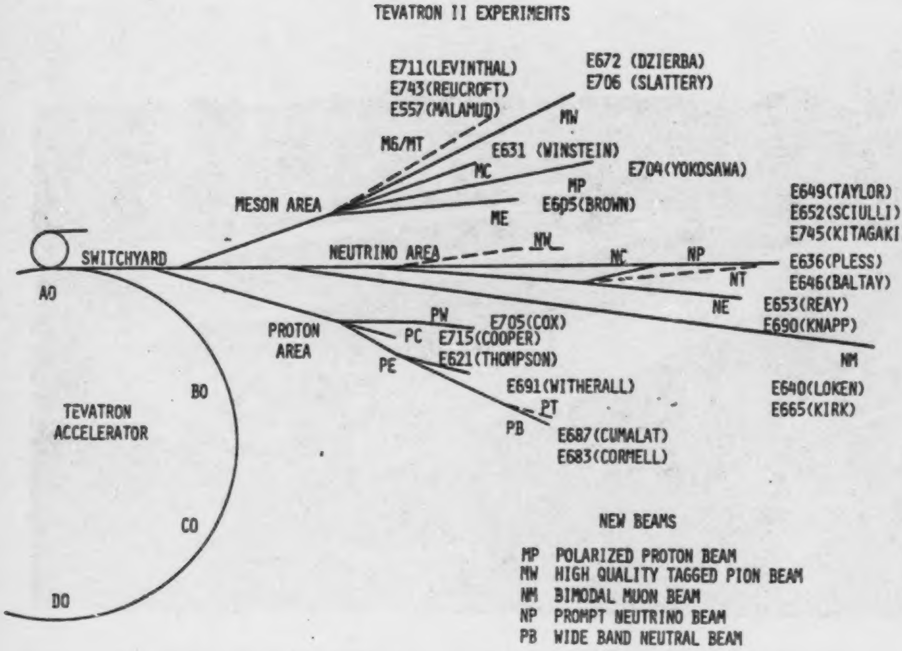
Peter S Cooper

Joseph Lach

Ed McCliment

John Marriner

THANK YOU FERMILAB!


TEVATRON II EXPERIMENTS
E711(LEVINTHAL)
E743(REUCROFT)
E557(MALAMUD)
E672 (DZIERBA)
E706 (SLATTERY)
MW
M6/MT
E631 (WINSTEIN)
MC
E704(YOKOSAWA)
MP
MESON AREA
E605(BROWN)
ME
E649(TAYLOR)
E652(SCIULLI)
E745(KITAGAKI)
SWITCHYARD
NEUTRINO AREA
NW
NC
NP
E636(PLESS)
NT
E646(BALTAY)
AO
NE
E653(REAY)
E690(KNAPP)
PW
E705(COX)
PROTON AREA
PC
E715(COOPER)
E621(THOMPSON)
PE
NM
BO
E691(WITHERALL)
E640(LOKEN)
PT
E665(KIRK)
TEVATRON ACCELERATOR
PB
E687(CUMALAT)
E683(CORNELL)
CO
NEW BEAMS
MP POLARIZED PROTON BEAM
MW HIGH QUALITY TAGGED PION BEAM
NM BIMODAL MUON BEAM
NP PROMPT NEUTRINO BEAM
PB WIDE BAND NEUTRAL BEAM
DO

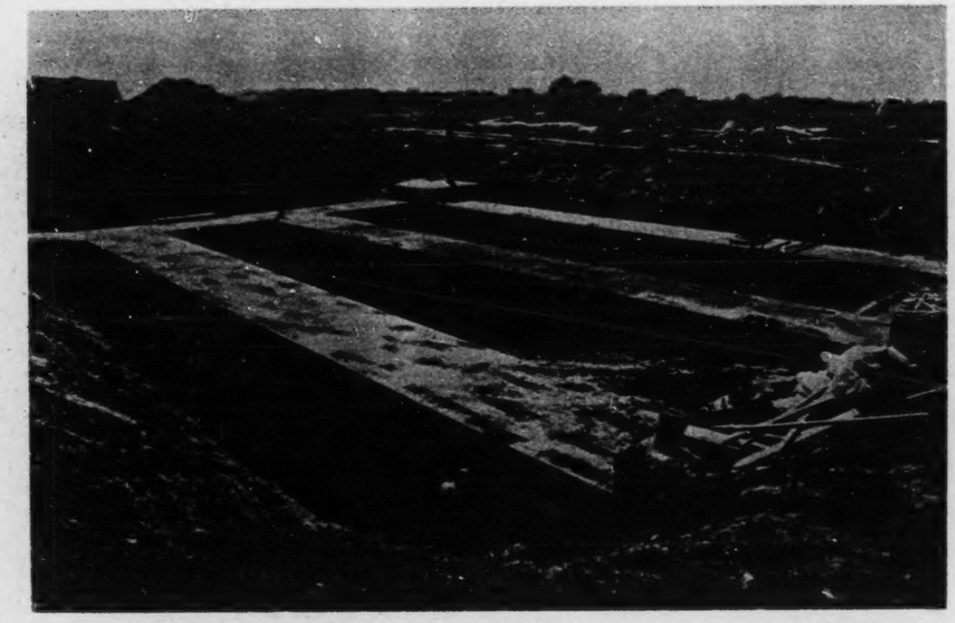
of the sigma minus come off in a particular direction. In addition to all of this data taking, two test beams are busy calibrating and testing apparatus for future runs.

In what follows, we touch on some of the highlights of Laboratory activities. In no way do we claim completeness.

Tevatron II

The Tevatron II Project is midway through its official lifetime, and (like other middle-aged organisms) there are some accomplishments behind, significant challenges ahead, and lots of present activity. The project end is also now visible and stimulates thoughts of mortality and the impulse to sum up the gains that will accrue at completion. Manager Tom Kirk and Deputy Ray Stefanski are the "summer uppers." Implementation takes place mainly in the Experimental Areas.

Nineteen eighty-three was a year of change for the Experimental Areas. It was the first full year after the reorganization that combined three previously separate departments into one. Hence, 1983 was a year for molding and testing the new organization, and the tests were not easy. Not only

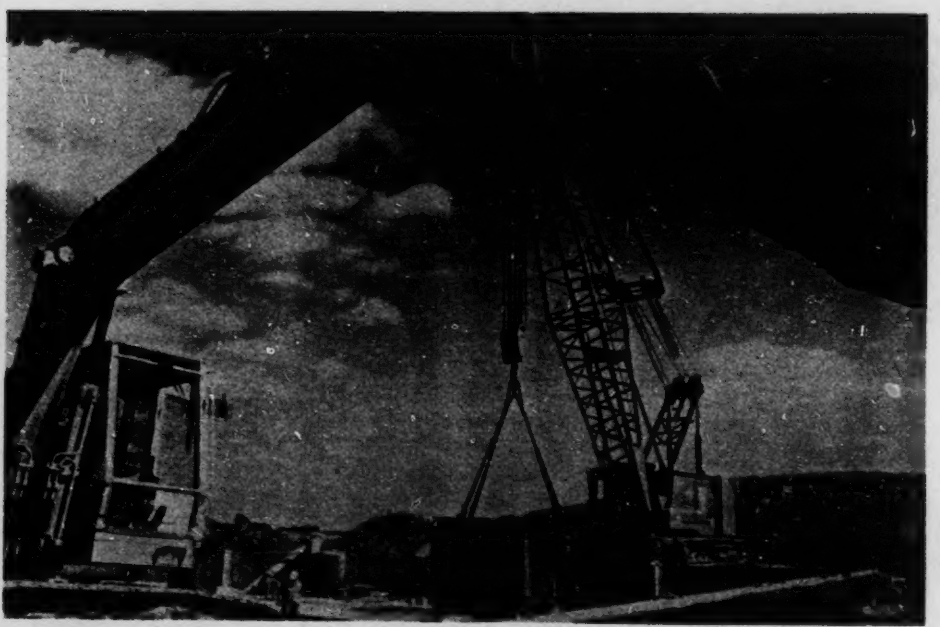


New Meson beam enclosure upstream of the Meson Detector Building.

did this group have the responsibility for implementing the beam line changes inherent in the Tevatron II program but they became an operating group as of October 1, 1983, with the responsibility for tuning and stabilizing the various beams which were required for the program.

To cap all of this, experiments due to run in the spring of '84 had to be installed when areas became ready. Direction of this group changed from the founding leader, Ken Stanfield (who moved to the Business Office), to Roger Dixon.

In the **Meson Area**, three beam lines have been rebuilt and are being commissioned. They are the new M-East beam line which presently serves E-605, the MT beam which delivers protons to E-609, and the MB beam which serves as a test beam for the old M4 area. Some of the major new components in these beam lines include five (5) cryogenic bends, 3 in ME and 2 in MT. A new cryogenic refrigeration center was constructed in the Meson Area to service these bend points. This center includes 3 satellite refrigerators. In addition, the beam enclosures just upstream of the Meson Detector Building have been modified to allow future installation of the new MW, MC, and MP beam lines. In the 1 TeV plan, primary protons for these beam lines will be delivered to target piles located in the detector building. A 3-way split to the Meson Area now exists in the

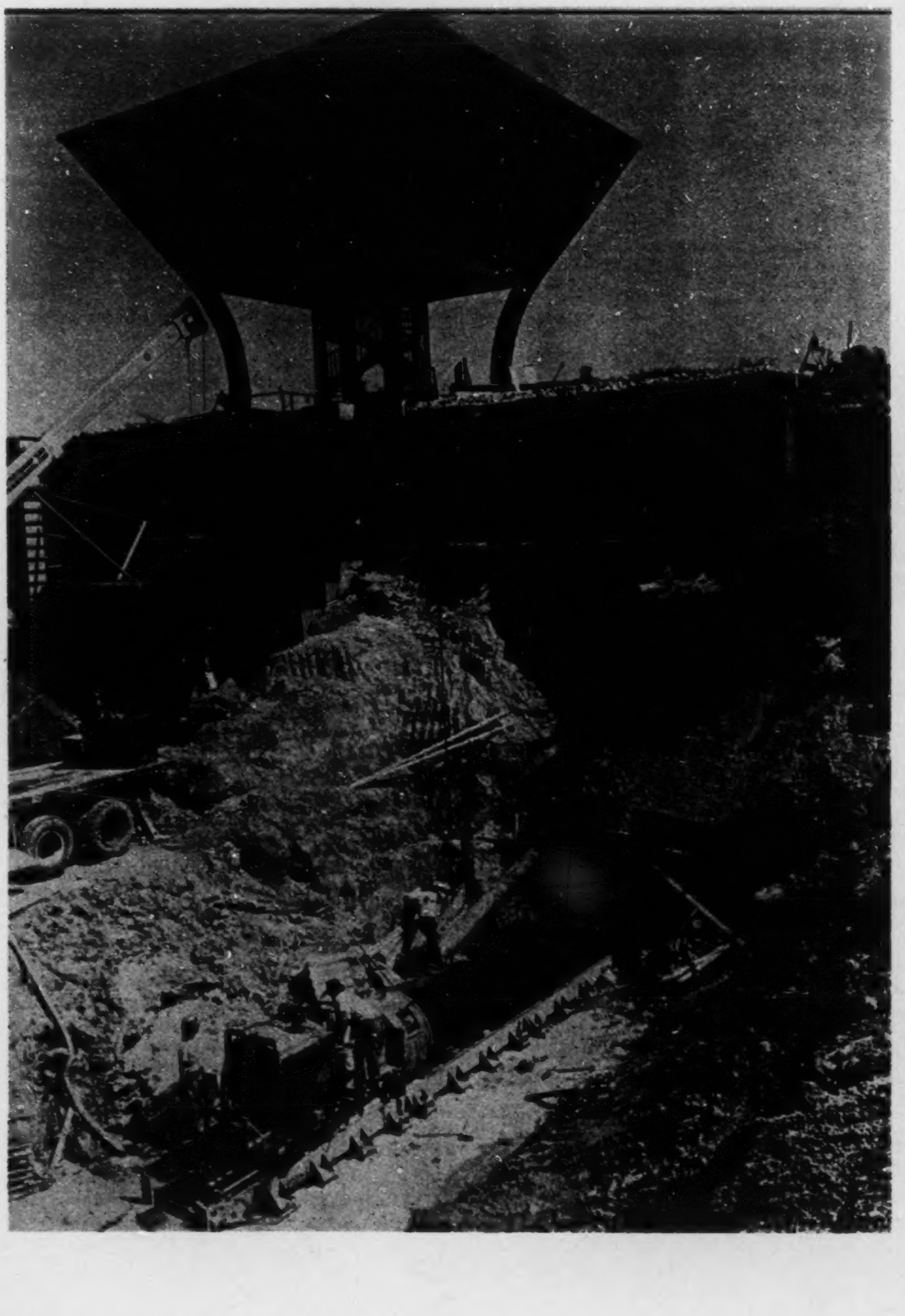


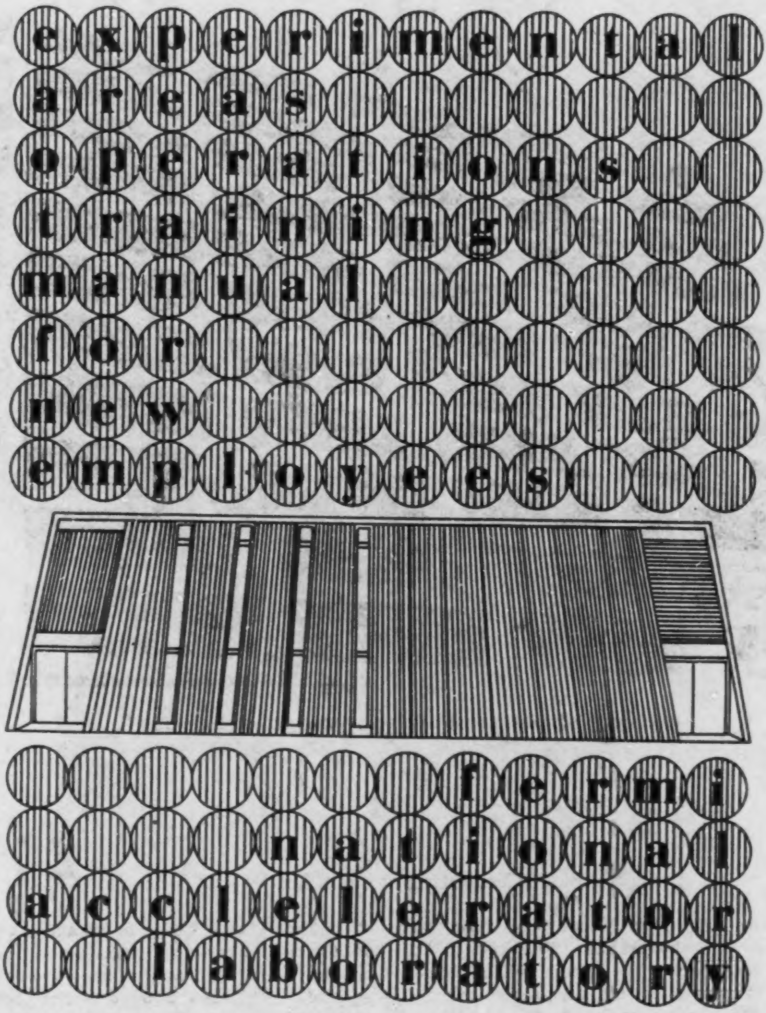
Installation of Tevatron II one-meter bubble chamber steel in Lab F.

switchyard. In the future it will be possible to run ME, MW, and one of MC, MP, or MB simultaneously and independently.

Neutrino Area activities include construction of Lab G, Lab F, and modification of Lab E. In addition, some of the upstream beam pipe for the new muon beam were installed as well as modifications to NW1 to accommodate the new beam. In preparation for the construction of the new Muon Laboratory, the Chicago Cyclotron Magnet was moved from the old muon laboratory and is being installed at the new laboratory. In the meantime, the old muon lab will house the NW test beam facility with many users lining up to make use of it. Other work in the Neutrino Area includes the construction of the new N-East hadron beam. This beam will be transported to Lab D for initial use by E-653. The bubble-chamber crews are busy outfitting the 15-foot bubble chamber with a new laser holography system that should provide 100-micron resolution in the chamber.

In the **Proton Area**, the three primary beam lines have been upgraded to 1-TeV capability. The upgrade included the installation of one new cryogenic bend string to service the PW primary beam line. Also, five superconducting quadrupoles have been installed in PE. One satellite refrigerator was installed for each beam line. In addition, a new enclosure (PE2) was constructed to house the



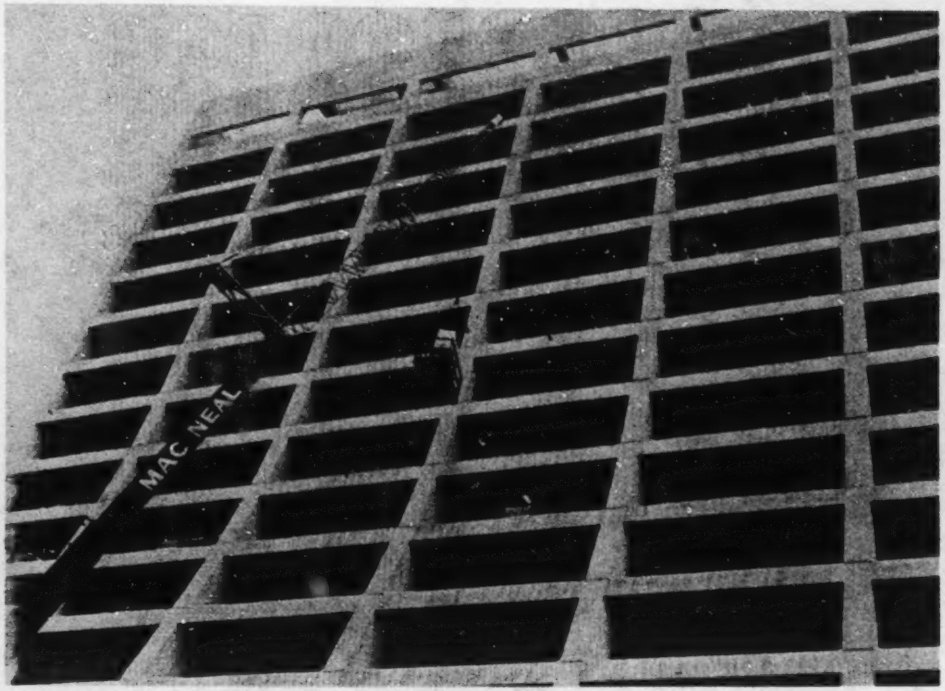


experimental
areas
operations
training
manual
for
new
employees

fermi
national
accelerator
laboratory

Lambertson magnets which will eventually split the new Wide Band Beam from the PE primary beam. A new quadrupole enclosure for P-Center (PC2) was also constructed as part of the same contract.

Since the reorganization, it was also necessary to consolidate the operation of the three areas. The Operations Center is temporarily located in the NS3 service building while a new building is being constructed just north of NS3. It is anticipated that the operations for the next physics run beginning in the fall of 1984 will be centered in the new Operations Center.



Delivery of new computer equipment to Wilson Hall.

Computing at Fermilab

During the last year, the load on the Central Computing Facility at Fermilab has grown to levels which have brought the system to complete saturation. This saturation had been projected to occur at this time when the present system of three Cyber 175's was ordered in 1979. Consequently we authorized the acquisition of additional equipment. For the acquisition, a fully competitive bid procedure was utilized. The winner was a dual Control Data Cyber 875 processor with 750K words of storage.

The new CDC hardware will be delivered stepwise over the next 20 months, first one CPU and then a second. It also provides for additional peripherals, including tape drives, disk drives, and printers. By the end there will be the equivalent of seven Cyber 175 CPU's installed in the Central Computing Facility. The additional disks to be delivered will more than double the presently available disk storage capability, bringing the total to 30 gigabytes.

Another major change in the Central Computing Facility is the addition of a Network Systems Hyperchannel local area network. This is a 50 megabit coaxial cable system capable of transferring files among all of the machines connected to it over distances spanning a few hundred feet. All the existing large computers currently installed on the 7th and 8th floors of Wilson Hall will be connected to this network. Thus, the existing Cyber 175 complex will be on the system as will the new 875 processor. In addition, the IBM business computer, recently changed from a model 4331 to a 4341, will be connected to the Hyperchannel. At the end of the year, two 4 megabyte VAX's with 2.7 gigabyte of disk storage capacity will also be installed and connected to the Hyperchannel. These VAX computers will serve as an alternate front end to any computer connected to the Hyperchannel for those users who prefer that route into the system. This facility will be particularly attractive for those programs which only run on VAX's.

The most important feature of the Hyperchannel is that once it is installed and working in a mature manner, it will be possible to add new computers into the network in a relatively straightforward manner. This will give us the future capability of adding powerful but not particularly user-friendly machines for additional compute functions.

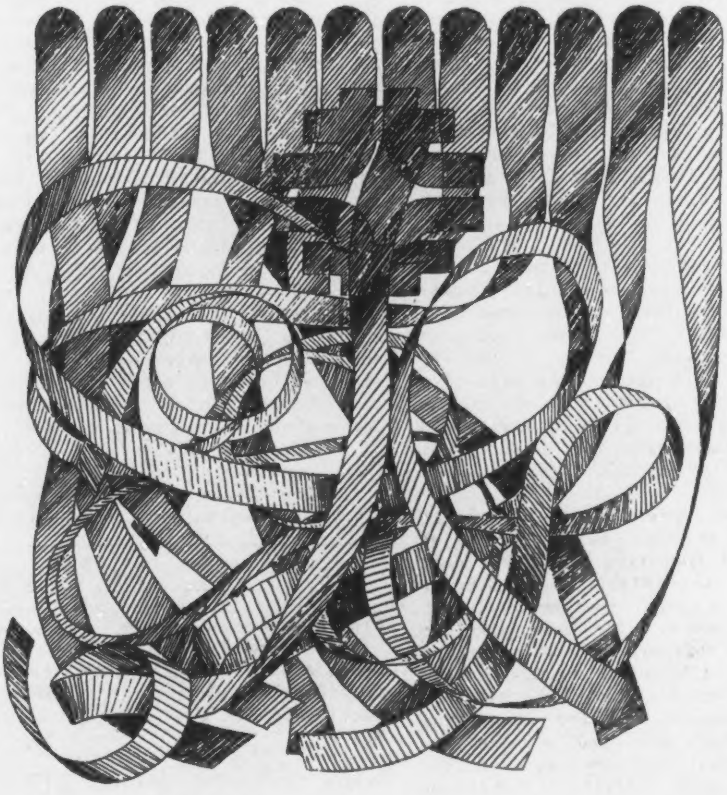
With the resumption of the experimental program this fall, the major effort in the Computing Department data acquisition and electronics support groups was to help experimenters with their experiments. The most significant part of this effort was in turning on systems with whole new architectures, consisting of coupled, multiple computer systems. The Computing Department has developed and is now distributing pairs of computers (either two PDP-11's or a PDP-11 front-ending a VAX 11/780) to the largest of the experiments. The Department's efforts have included the integration of new hardware and the development of a large amount of new software. This new software is built on the software which is still in wide use in the good old single computer systems.

Just as the data-acquisition computing has required significant new extensions of capability, so too has the electronics which resides between the particle detectors and the computers at the experiments. The international high-energy physics community has combined efforts to develop a new standard, called FASTBUS, which is directed at the specific distributed processing needs of the future detectors in this field. The Computing Department has participated in defining the specifications for this system, in evaluating prototype devices, and in preparing the software to use them. The software efforts in the Department include work on drivers for computer interfaces, general subroutines, a higher level interpretive language, and a data base and other system management tools. The Department also shoulders the responsibility for drafting and maintaining the internationally used standards for FASTBUS software. Commercially available FASTBUS devices are also beginning to enter the electronics pool and training of personnel on these new devices has begun in earnest.

Projection of Computer Needs
In Equivalent CYBER Hours

	1984	1985	1986	1987
Proton Area	3	4	5	5
Neutrino Area	1	1	1	1
Meson Area	1.5	1.5	1.5	1.5
Collider	1	3	10	16
Accelerator	1	1	1	1
Theory	*	*	*	*
Sums	7.5	10.5	18.5	24.5

Looking further ahead, we convened a new Computer Advisory group chaired by Joe Ballam of SLAC and composed not so much of users as of computer professionals. The Ballam Report looked towards 1986 and confirmed our worst fears--the colliding detectors observing 2-TeV collisions would swamp the system many times over. Their recommendations are very sweeping and a new acquisition study (looking towards '86) is underway to cope with the problem. In parallel we are trying to develop specific computer architectures for our own specific problems. To this end we have formed an **Advanced Computer Program** group under Tom Nash. This group is designing a processor with track reconstruction and other Fermilab specific problems in mind. Close liaison with CDF and other customers is essential. This brings up **CDF**, one of our major construction projects. It gets a special section further on in this annual report.



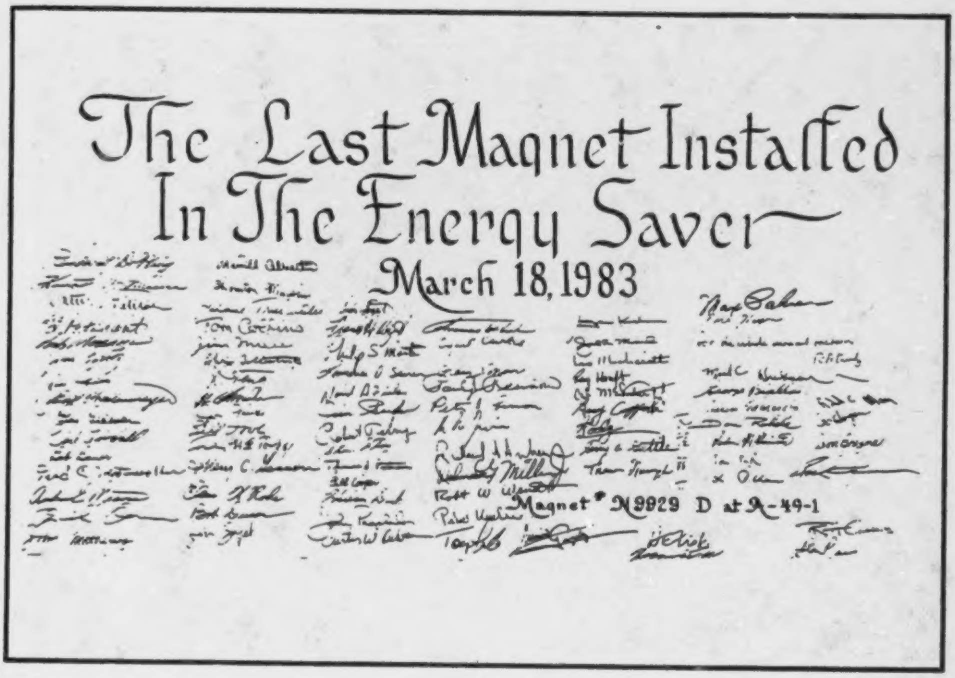
Report of the Ballam Committee December 1983

Helen Edwards signs placard seen on the facing page. Her article on "The Startup of the Energy Saver" is next in this report.

Technical Support Section

The Technical Support Section is a 1983 invention and is composed of groups whose nearly total commitment during the past four years has been the production of superconducting magnets and other components for the Energy Saver. The high point of 1983 was the delivery of the final magnet for the Saver ring, followed by the remarkably successful commissioning. Early in 1983 the completion of this work allowed a shift of emphasis from the Saver to the Tevatron I and Tevatron II projects. These new projects require the construction of nearly 700 conventional magnets and a large number of complex beam electrodes for the antiproton source and for higher energy beam lines for the experimental areas. The merging of the conventional magnet effort with the superconducting magnet facility, the mechanical design group and the machine shops to form the Technical Support Section was in fact a way to meet the challenge of the TeV I and TeV II project schedules. This was done in 1983 and the section entrusted to the direction of Richard Lundy with Paul Mantsch as his deputy. The bulk of production manpower that once built Saver magnets is now hard at work on TeV I and TeV II magnets.

Although the final production and measurement of the Saver magnets was completed in February of 1983, a



The Last Magnet Installed
In The Energy Saver
March 18, 1983

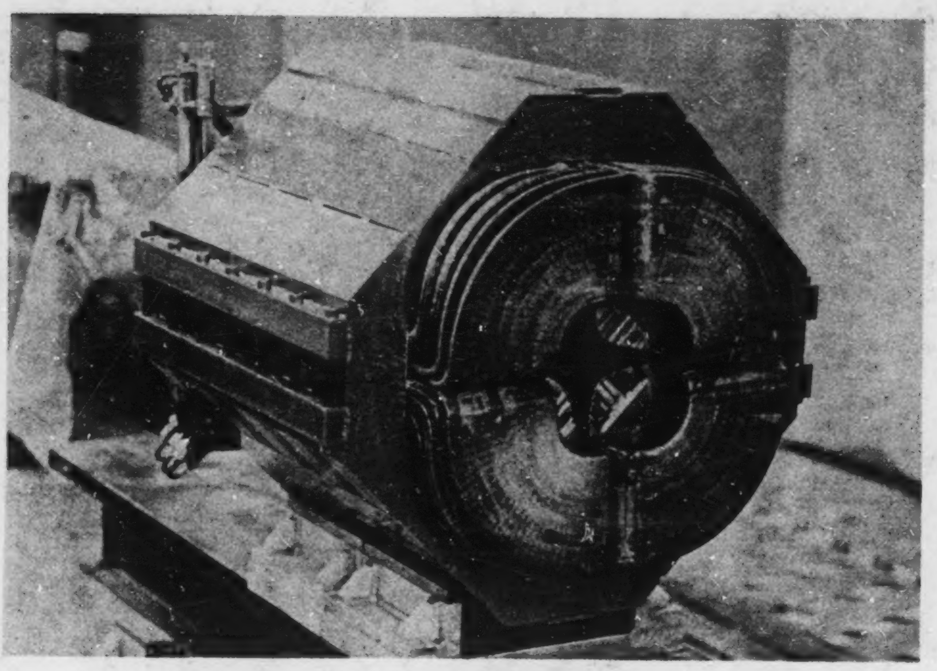
Magnet # N9929 D at A-49-1

reduced work force remained to build spares as well as special purpose superconductor magnets. In particular high gradient quadrupoles needed for the colliding beams interaction region were built and tested.

The Tevatron I project consists of the production of over 400 conventional magnets that make up the debuncher and accumulator rings as well as beam lines within the antiproton source. There are two sizes of quadrupoles and two sizes of dipoles. Each of these come in various lengths. Once complete, the magnets will be measured magnetically at the Magnet Test Facility using a newly designed data-acquisition system incorporating substantial improvements arising from our experience with measuring over 1000 Saver magnets.

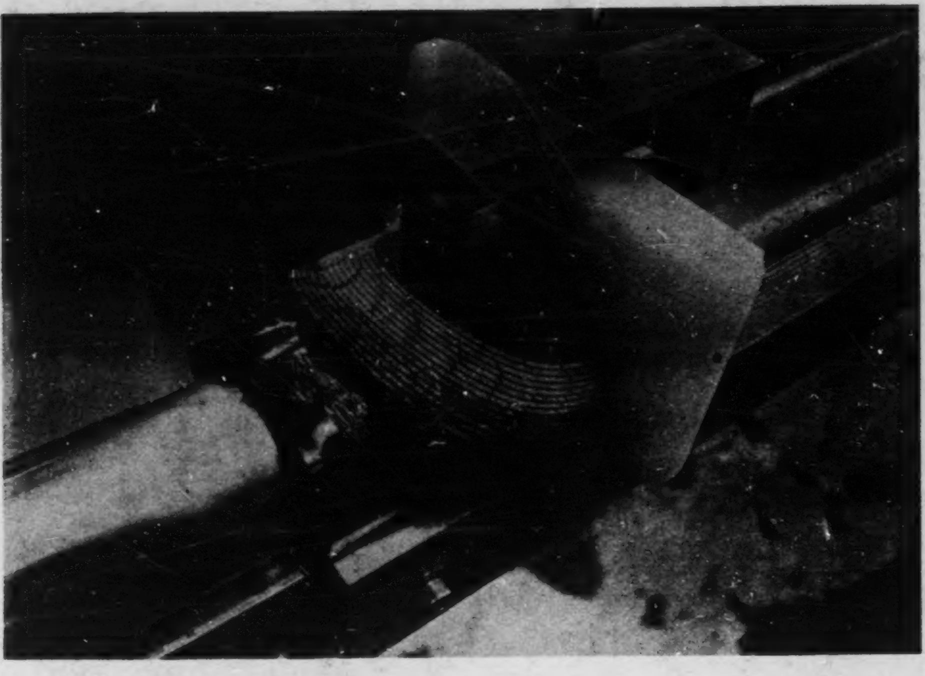
Technical Support also started the fabrication of the beam pickup electrodes which are the heart of the antiproton cooling system. A fully electronic "traveler" (a quality control document) was introduced to monitor electrode production by presenting assembly steps and recording quality control measurements.

The Tevatron II effort consists of providing a variety of magnets for upgrade of the beam lines for 1000-GeV beam. There are about 275 new conventional magnets built for this purpose. An additional 50 Saver-type magnets were placed in the beam lines.

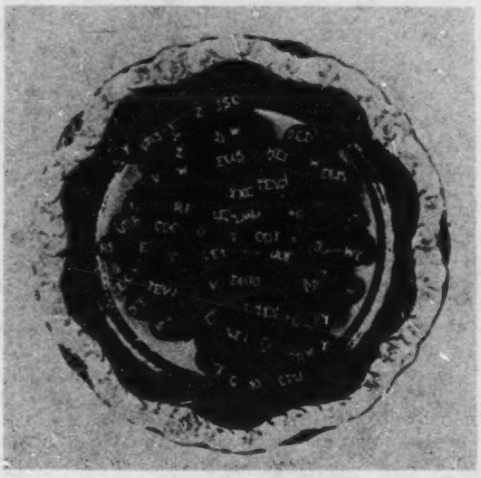


Prototype quadrupole for the Tevatron I project. Note shaping of the poles at the ends.

During 1983 an effort was started within the Technical Support Section to develop magnet designs for the Superconducting Super Collider (SSC). The unique contribution which Fermilab can bring to this project is of course our recent experience with the Energy Saver. Although effort has been invested in both high field (8-10 Tesla) and superferric (2-3 Tesla) magnets, the focus of the work is an extrapolation of design concepts proven in the Saver. The program of magnet development that was undertaken included magnet design, field calculations, structural analysis, and an extensive modeling program. The goal of these activities is to build and test a string of production prototype SSC magnets in a period of three years.



Coil of a 2-in. superconducting dipole prototype.



Two stages in the Tevatron I tunnel construction. Roof beams have been put in place in the lower photograph.

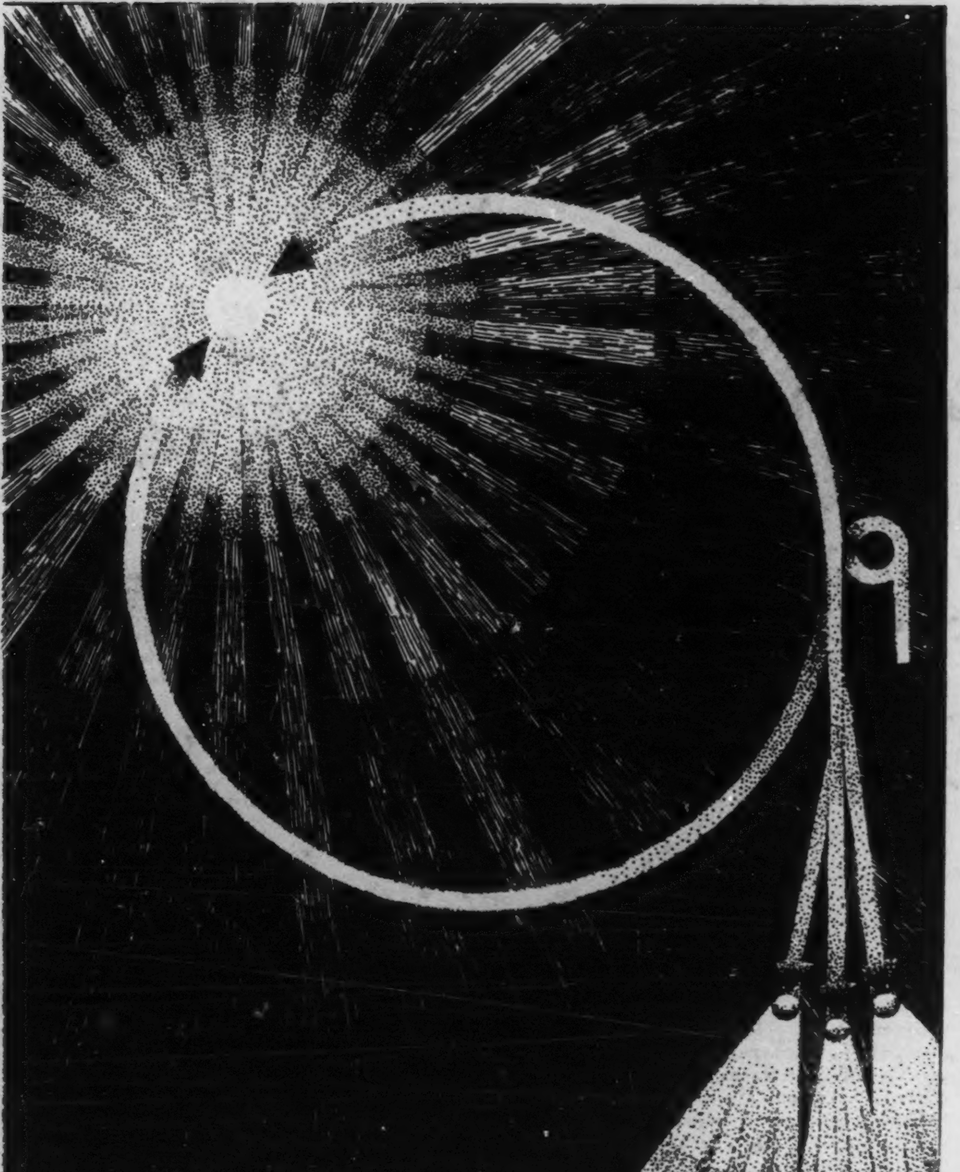
Aerial view of the Tevatron I tunnel construction.

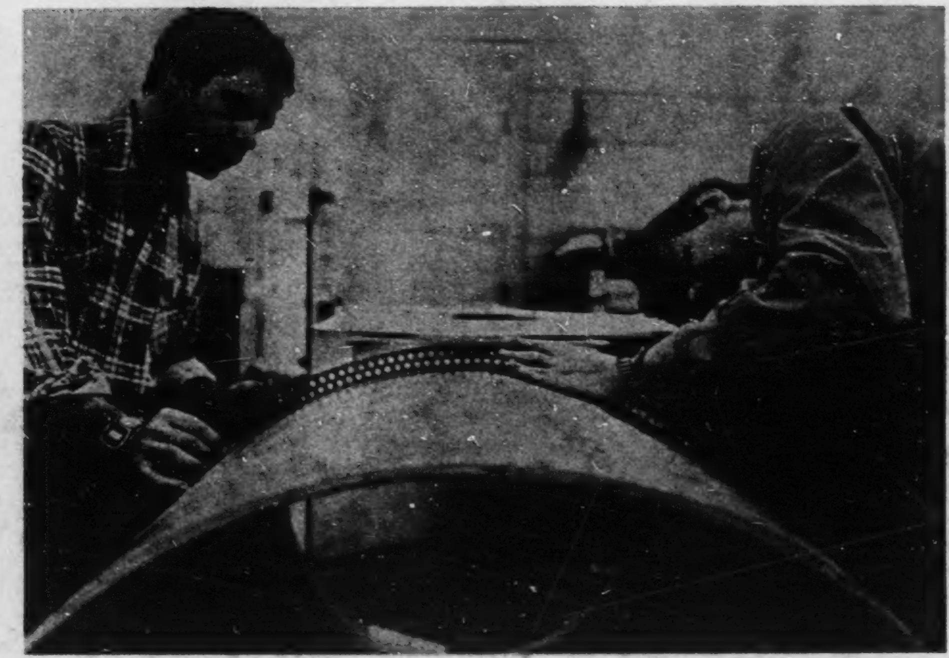
Tevatron I

The year 1983 saw the Tevatron I project make a great leap forward toward our goal of colliding-beams experiments with 1-TeV protons and 1-TeV antiprotons. The project, under John Peoples and Don Young, has moved from a largely design phase to a mature phase of construction and fabrication. Some of the impetus for our advance came from external events, but the largest factor was certainly the inspired perspiration of everyone working on Tevatron I.

First, the external events. The great success of the CERN SPS Collider and the important physics results in 1983 from that work confirmed what we already knew, that there is gold to be mined in the hills of $p\bar{p}$ physics at our higher energy. The CERN work shows that we are building a feasible system for doing physics. Considerable theoretical work gives hints of interesting new phenomena in our energy range. In addition, the HEPAP-DOE decision to press forward with the Superconducting Super Collider as the step for the 1990's gives Tevatron I additional importance as the U.S. hadron-hadron collider of the 1980's.

These bright stimuli pale into insignificance compared with the drive



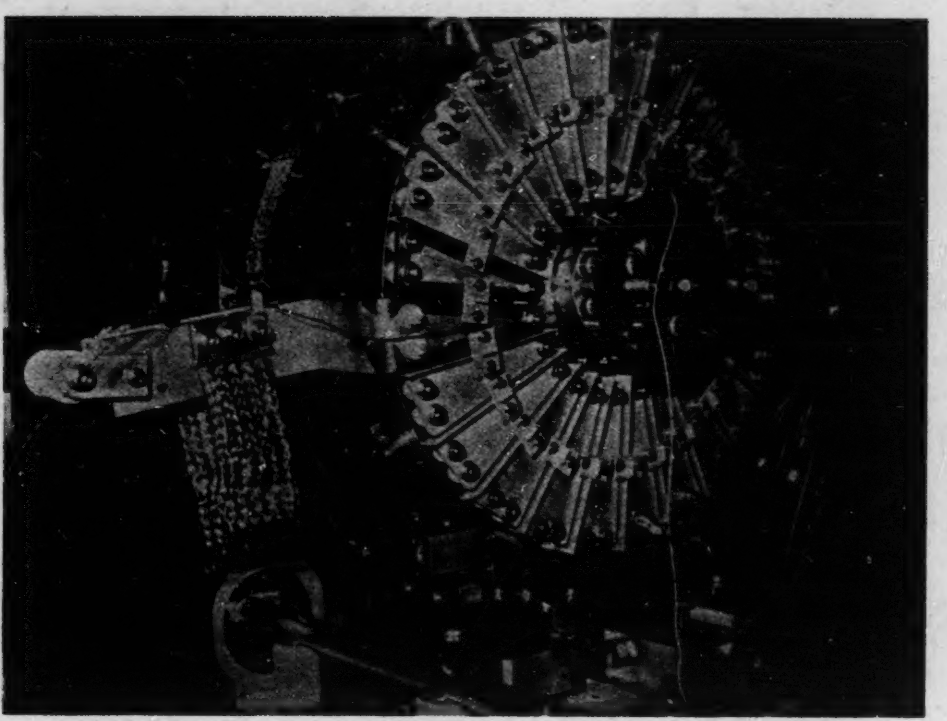


Tom Petrak (left) of Meyer Tool and Joel Misek assemble a prototype Tevatron I rf cavity.

◄——————————— Cover from the Tevatron Phase 1 Project Design Report.

of the Tevatron I people to move their project along. In 1983, this drive has produced prototypes of all the major pieces of hardware in the antiproton source. In addition, the experimental hall at B0 has been completed and is now in use by the Laboratory.

The low-beta superconducting magnets that make the beam neck down to a small waist for high luminosity at B0 have been built and testing is virtually complete. These magnets have higher fields and are more difficult than the ordinary superconducting magnets of the Tevatron ring. Design work is going on for an equivalent low-beta system for the D0 interaction region. We are also working on designing and building equipment for the overpasses that will

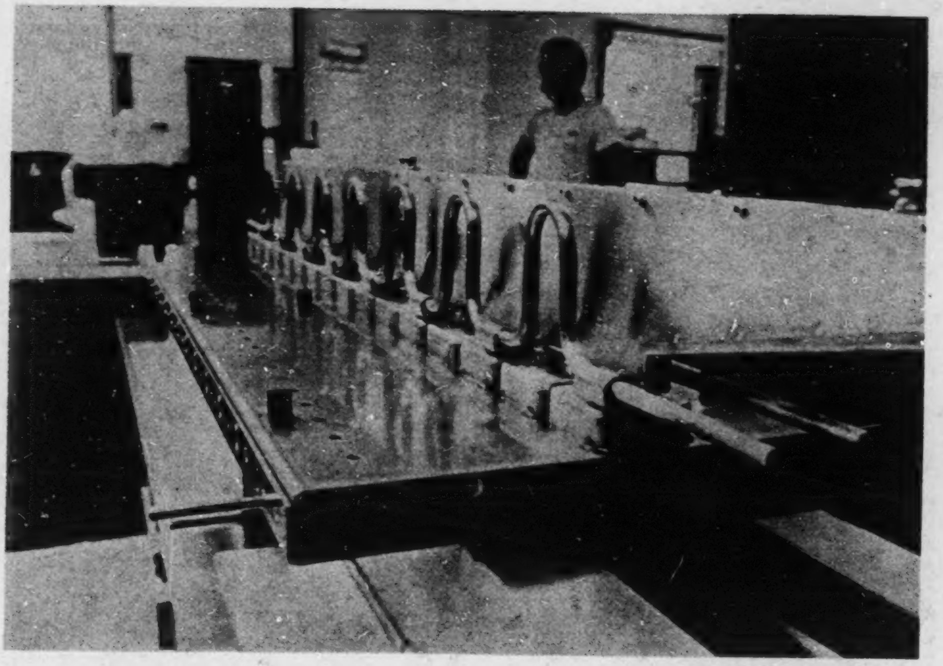


The Fermilab lithium bus and transformer mounted at CERN for testing. The lens can be seen jutting out from the transformer aperture. Water-cooling lines have not been connected in this photograph.

carry Main-Ring beam around the detectors at B0 and D0. It goes without saying that in all of this, TeV I is Technical Service's best customer and vice versa.

The architectural design of the ring and beam-transport enclosures, the roads, and the utilities were completed and construction of these facilities is in full swing. We will begin the installation of equipment in them in the spring of 1984. This design work was held up for a time in 1983 because our detailed orbit studies showed us that some design changes were needed in the Debuncher lattice and these changes affected the tunnel dimensions.

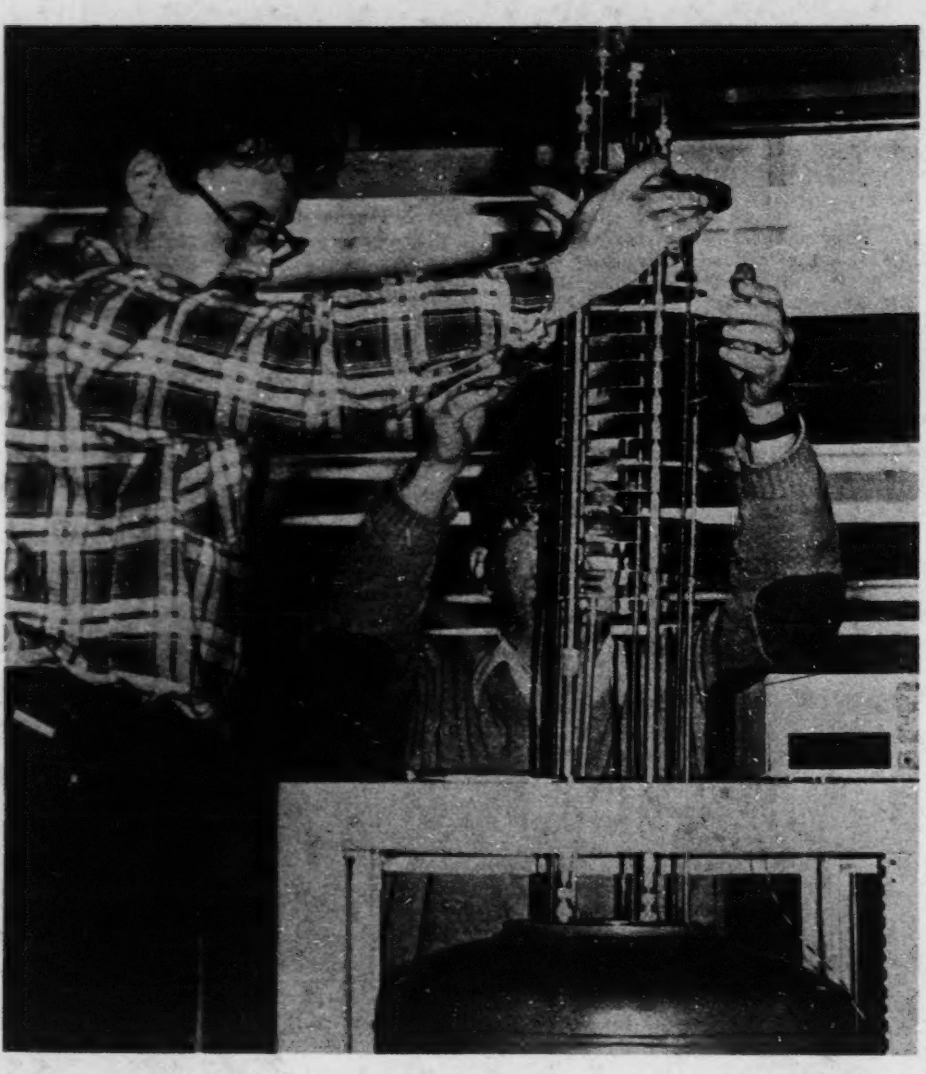
One of the many gratifying areas of advancement was the lithium lens used to focus antiprotons immediately downstream of the production target. The lithium lens, invented at Novosibirsk, is a challenging component because of its very large pulsed current and very large internal stresses. Our group built its own lithium lenses in 1983 and, after pulsing tests here, took one to CERN for testing in their



Prototype of a stochastic-cooling pickup for Tevatron I.

antiproton production system. These tests were successful—the lens performed according to design, giving us confidence in our entire production scheme.

Another difficult system that has made significant advances in 1983 is the stochastic-cooling hardware. Complete prototypes have been built and tested for the 1 to 2 GHz range, including, pickups, amplifiers, filters, and kickers. Their performance has reached the design goals. Work is also going on in the 2 to 4 GHz range. Here the prototype systems are close to the design goals. Included in this work is a new design feature, the use of superconducting notch filters constructed from a 330-m long transmission line. The filter is used to shield the core of accumulated antiprotons from the thermal noise generated by the very high gain stack tail cooling system. This work is a collaboration among our own group, Lawrence Berkeley Laboratory, and Argonne National Laboratory, and all have made solid contributions to the joint effort.

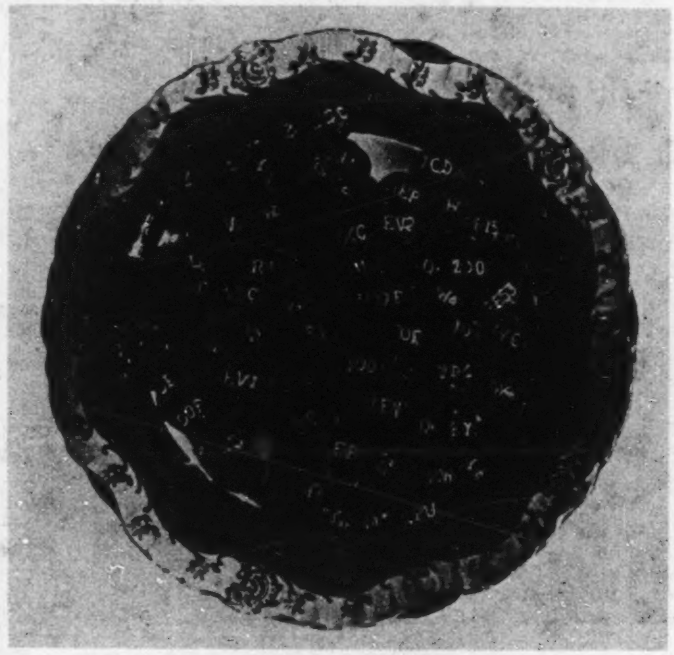


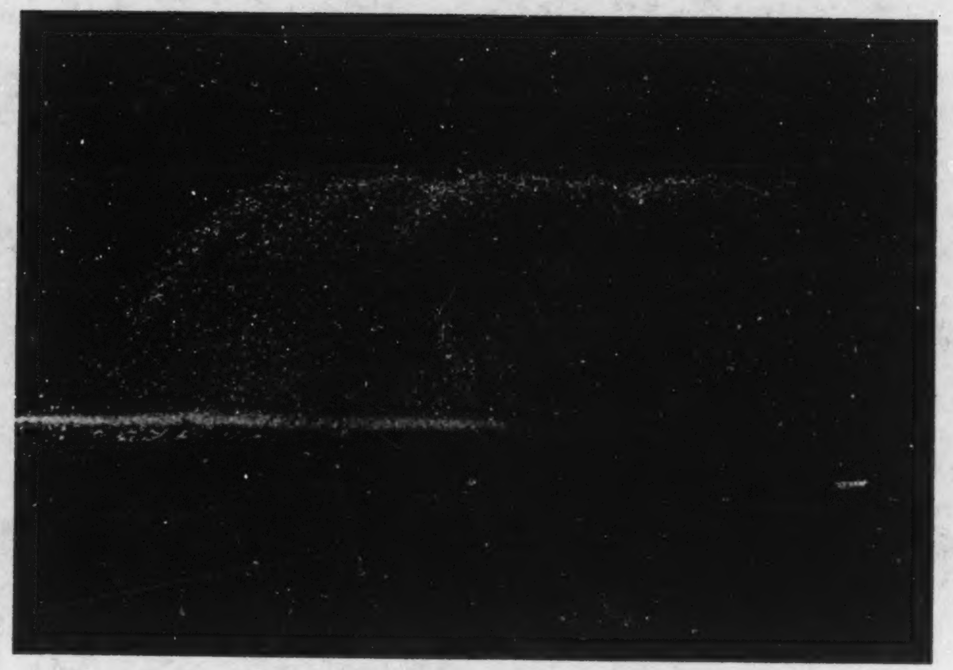
Ralph Pasquinelli (left) and Moyses Kuchnir lower a superconducting stochastic-cooling filter assembly into a dewar for tests.

We have already mentioned the conspiracy between TeV I and Technical Support to build 400 serious and multitudes of smaller magnets for the Debuncher, Accumulator, the many beam-transport lines, and the overpasses.

Many other components, such as kickers and rf cavities, have been tested experimentally in prototypes and are now being ordered for production. We have also ordered vacuum components, power supplies, control-system components, and many other parts for the antiproton source rings.

A year from now we will have completed the ring and will be deep in the throes of commissioning the Antiproton Source. The goal is to see the first $\bar{p}p$ collision in the Tevatron at 2 TeV in the center-of-mass before the 1985 shutdown begins.





A fountain in the Main-Ring cooling pond.

Business Services Section

This was the year that Yale University hired away our Business Manager, threatening a total breakdown of Laboratory operations. The crisis reminded us of a truism that the section which works best makes no trouble and does not appear in our annual review. We plotted a war on Yale. Cool heads prevailed and Ken Stanfield was bribed to take over provided he was helped by Jim Finks. Here is what he found out.

Because of the major construction projects (TeV I, TeV II, and the Saver), procurement activities for FY1983 increased 12% over FY1982, for a total of 29,176 requisitions. The dollar value increased 59% for a total of $97.8M. Several major contracts were awarded including the Antiproton Ring Enclosures, the Industrial Center Building, and the Large Computer Facility Augmentation.

All of this purchasing and contracting activity was reflected in an increased workload for Shipping and Receiving, which receives materials, and Accounting, which pays the bills.

Plant Maintenance activities included renovation of the Central Utility Building--painting inside and out, repair of pipe insulation and lines, etc. The Village natural gas system was also refurbished and cathodic protection added to all main lines.

Highlights of activities performed by Site Services include road and landscaping improvements, move of the brick Security Office to Site 50 because of muon tunnel work, repair of the ring pond dike system, several energy management projects, and upgrading of the pumping station at Casey's Pond. Additionally, the following facilities have been completed: Booster Gallery East Addition, shop facilities for Plant Maintenance, Magnet Storage and Assembly Buildings, and a new gymnasium. These items, plus structural maintenance throughout the Laboratory, nearly doubled the volume of work performed by the Time and Materials group to $6.2M.

The Information Systems department is responsible for much of Fermilab's administrative data processing, particularly those applications of a business nature. Due to their efforts, we can look forward to automated purchasing, accounting, and requisitions systems in the future.

Yes, Virginia, there is a Business Services Section.

Safety Section

Another vital cog, left out of several annual reports, is SAFETY. This Laboratory takes safety very seriously. In 1983 leadership passed from unsung hero Lincoln Read to not even (yet) unsung hero Larry Coulson.

1. Radiation Safety

The total personnel radiation dose for the Laboratory continued to decrease, as it has steadily since 1974. The 1982 total was 110 person-rems, and since protons were not accelerated during most of 1983, this year's doses have been considerably lower. The dose levels we experience are well below the permissible levels set by the U. S. EPA and DOE.

Radioactive waste storage and handling systems have been improved. Over 14,000 cu. ft of radioactive waste was shipped for burial for FY1983. A higher capacity solar evaporator was constructed this spring, and 1900 gallons of tritiated water was evaporated, resulting in a considerable cost savings.

The 4th Edition of the Radiation Guide was issued in May. A number of changes in requirements and procedures have been made to reflect the changing nature of radiation safety problems at Fermilab.

2. Environment and Safety

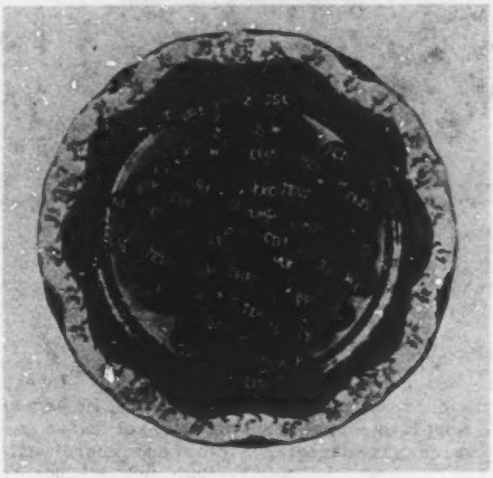
Occupational injury rates fell dramatically compared to previous years. This change is attributed to programmatic follow-up of work injuries. Below is a table showing the Total Reportable Case (TRC), Lost Work Case (LWC), and Lost Work Day (LWD) rates for 1982 and 1983. Rates are normalized to incidence per 200,000 person-hours.

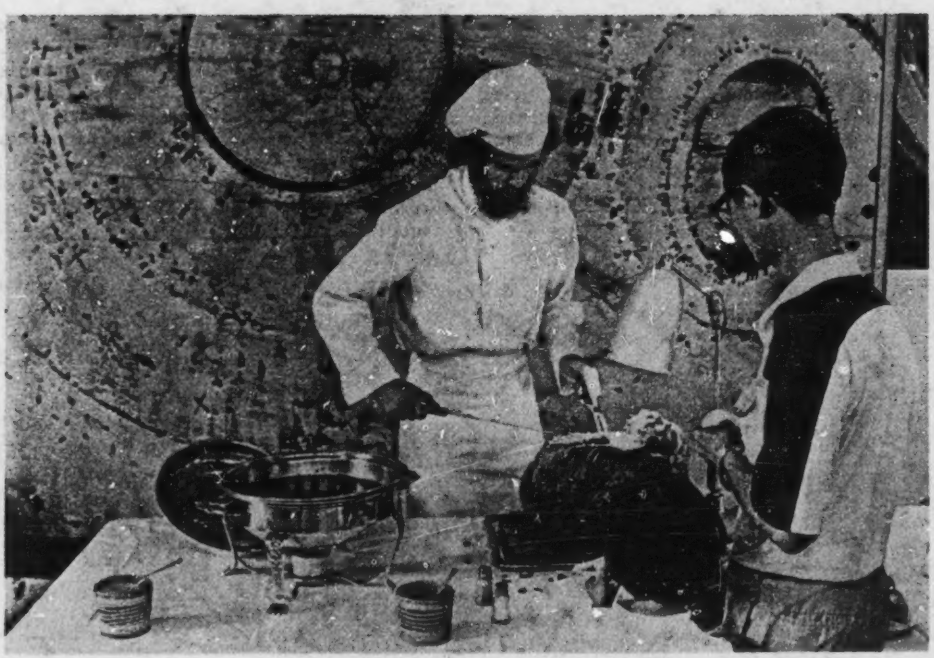
Index	1982	1983*
TRC	2.4	0.87
LWC	2.3	0.66
LWD	16.6	4.7

*Statistics collected through third quarter

The Lab's industrial hygiene program got a big boost with the addition of an industrial hygienist and two industrial hygiene coop students. Day-to-day problems such as sampling the industrial environment and consulting on exposures are now handled in a timely fashion. In addition, a systematic review of industrial hygiene hazards has been initiated to more precisely characterize the working environment at the Lab. Reviews of personal protective equipment, chemical carcinogens, cyanide plating operations, and teratogens have produced numerous improvements.

The extensive use of liquefied gases in superconducting systems has caused the Lab to adopt rigid controls to prevent suffocation from accidental leaks. The Lab has developed and built area oxygen monitors which are superior to those available commercially. The approximately 150 monitors are employed largely in the accelerator ring and associated areas.





King Yuen Ng and daughter are being served at an evening event during the 12th International Conference on High-Energy Accelerators held at Fermilab in August.

Laboratory Services

Man and Woman do not live by quarks alone, they crave bread and wine and other things supplied by Lab Services, and Lab Services is directed by Chuck Marofske.

Laboratory Services is responsible for human resource support activities of the organization. Specific functions are quite varied in resonsibility and include housing, food services, employee recreation, library services, photography, duplicating, publications, medical, employment, personnel administration, equal opportunity, and public information.

Certainly one of the highlights of this year's activity was serving as host to the International Accelerator Conference in August. The Publications Office served as a conference organization and coordination center. We also organized a Laboratory open house event in September and welcomed close to 10,000 visitors on a Sunday afternoon. This was the third open house event in Laboratory history and it featured tours of facilities, pictorial displays and presentations by staff members.

During the past year we expanded our capabilities in video presentations to augment training efforts, introduce a series of supplemental retirement annuity options for employees, and added another HMO option to the employee benefit program.

Light parabola sculpture, the creation of Charles Derer, a College of DuPage instructor, for the 12th International Conference on High-Energy Accelerators, held at Fermilab in August, 1983.

Programs to provide student learning experiences at the high school and college level continued as an active adjunct. General employment levels continued to grow and the emphasis on advance technology in recruiting intensified. Attention to the special requirements for workers entering the Main Ring enclosure to perform activities necessitated the implementation of new medical testing practices in the occupation health services offices. Many employees and candidates were tested against standards set for tunnel work activities.

Our day care facility received attention from schools of education as a model resource for practical student learning experiences.

These are just some of the events which provide diversion from our ongoing regular responsiblites to keep the human resources of the Laboratory effectively capable of meeting the challenge of producing new science.

Fermilab Astrophysics Group

This novelty was briefly mentioned in our previous Annual Report. It is led by Edward (Rocky) Kolb and Michael Turner.

The Theoretical Astrophysics Group at Fermi National Accelerator Laboratory is jointly funded by NASA and Fermilab. The offices for the group are located in Wilson Hall on the west side of the building, interspersed among the offices of members of the Theory Group. Although the group is administratively not part of the Theory Group, there is substantial overlap in the interests and work of the two groups.

At present, the group consists of two staff members, three postdocs, a secretary, and one permanent part-time visitor. The visitor position will be filled by an 18-month visit by Alex Szalay, starting in June 1984, and a 2-month visit by Bernard Carr, starting in April 1984. In addition, David Schramm spends approximately one day per week at Fermilab. The arrangement with Schramm is expected to continue indefinitely.

Inner Space/Outer Space

Fermi National Accelerator Laboratory May 2-5, 1984

This page is printed on stationery for Inner Space/Outer Space, a Conference on Physics at the Interface of Astrophysics/Cosmology and Particle Physics.

The group sponsors a weekly Astrophysics Seminar, which is usually given by people invited from outside the Laboratory, and a weekly Astrophysics Lunch where more informal reports and talks are given (usually by Fermilab personnel).

Plans are being made for a large conference on "Physics at the Interface of Astrophysics/Cosmology and Particle Physics" to be held at Fermilab on May 2-5, 1984. (This will be the first large conference on this subject.) The meeting was originally planned as a small workshop, but the response to the initial announcement was so great that we have changed it to a conference format.

The goals of the group are manifold. The foremost goal of the group is to do exciting and visible science at the interface of particle physics and cosmology/astrophysics. In particular, the latest experimental and theoretical developments in particle physics will be exploited to further our understanding of the origin and large-scale structure of the universe. In addition, cosmological and astrophysical data will be used to place constraints on particle physics theories [by using the results of the big-bang experiment (E000)]. Although the main thrust of the group will always be astrophysics related to particle physics, some effort will be made to keep the Fermilab scientific community aware of breakthroughs in other areas of astrophysics.

Research in the group at present is being done in the areas of inflation, galaxy formation with exotic particles, monopoles and astrophysics, cosmology of theories in more than four dimensions, cosmological effects of supergravity, and high-energy cosmic rays.

Local Organizing Committee

E. W. Kolb/M. S. Turner (Chair) D. Lindley, K. Olive, C. Quigg, D. N. Schramm, D. Seckel

Prospice

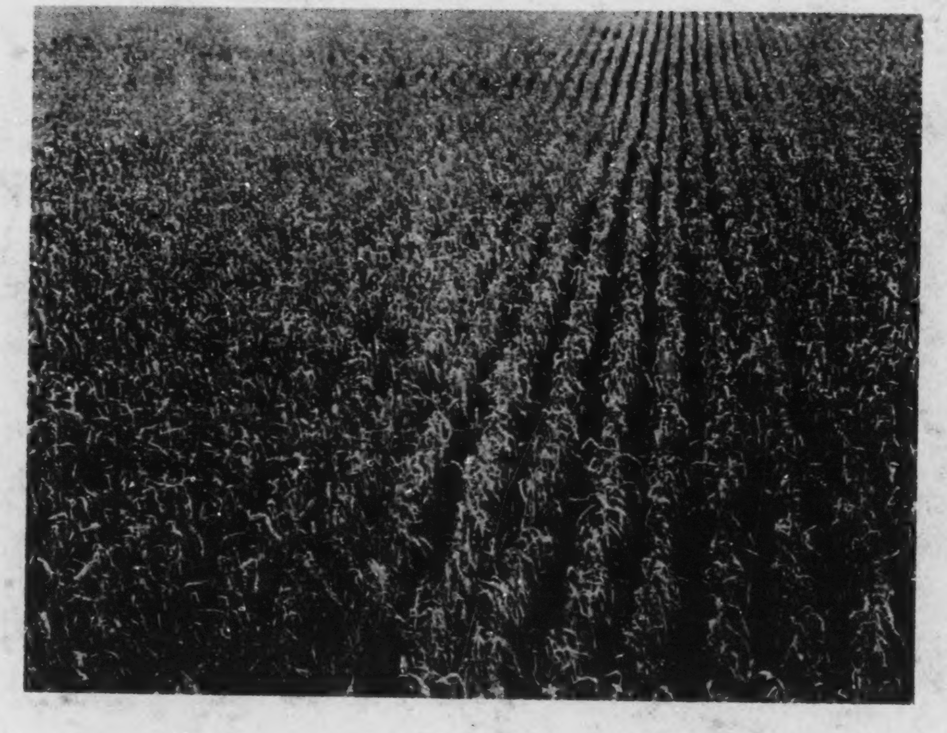
What is in store in eighty-four? During the summer shutdown (to build the proton beam line which will produce $\bar{p}$'s for TeV I and several other projects) we will fix Saver devices that need fixing and strive for as high as energy as we can reach. This may involve replacing some weak magnets. Another longer range prospect under design is to lower the temperature of the helium coolant by about one-half degree in order to gain about 100 GeV of magnet field. This will involve a major upgrade of the refrigeration system but will see only conceptual design in '84.

The experimental program for the fall of '84 will be even richer than the spring program. We hope to have ten experiments take data in that running period. The crucial issue is the funding level required to carry out the program. Funny that we didn't mention it but '84 will be a difficult year. Although it's difficult to reconcile the words "crucial" and "boring," the funding issue is both and, except for this brief record, more for history than anything else, we skip to a more fun theme: the SSC.

In spite of what appeared to us as agonizing slowness, the prospects for building a 20-TeV hadron collider have substantially improved since January of 1983. Notably, the HEPAP decision in July was to put forward the idea of the SSC as its highest priority. In the fall, the DOE in principle accepted the idea by offically asking Congress to reprogram funds for SSC R&D. The conceptual schedule as we now can guess it is to have a management consortium identified and an R&D director appointed by spring of '84. This parallels a paper reference design to be completed by May 1, '84. Meanwhile, all the laboratories have some assignment recognized by DOE but, hopefully, to be coordinated by the SSC R&D Director as soon as he or she is appointed. Fermilab is scraping every pot to free up talent for its contributions. Technical Services under Dick Lundy and Paul Mantsch had been working on a 5T magnet based upon the Saver design. Joe Lach heads up a small group looking at the possibility that Fermilab could provide the injection for the SSC ring. We are aided by the Geological Survey and by other State agencies, since the Governor of Illinois seems convinced that the Higgs problem should be solved under the cornfields of Kane County. We are obligated to study this question.

We should be very pleased with 1983. The Tevatron (nee Saver) has all the earmarks of working. The long range future of the field is to our tastes. Whereas I began this review by mocking our own seemingly perennial concerns with funding, I do remain convinced that this is a very serious determinant in our ability to get physics out of the Tevatron. Nichevo! The science is tremendously exciting. I'd like to steal a few paragraphs from our new, firm, unwavering five-year plan, forced out of our secret places by DOE requirements. There, where it says to fill out the form: Director's Overview, I scribbled:

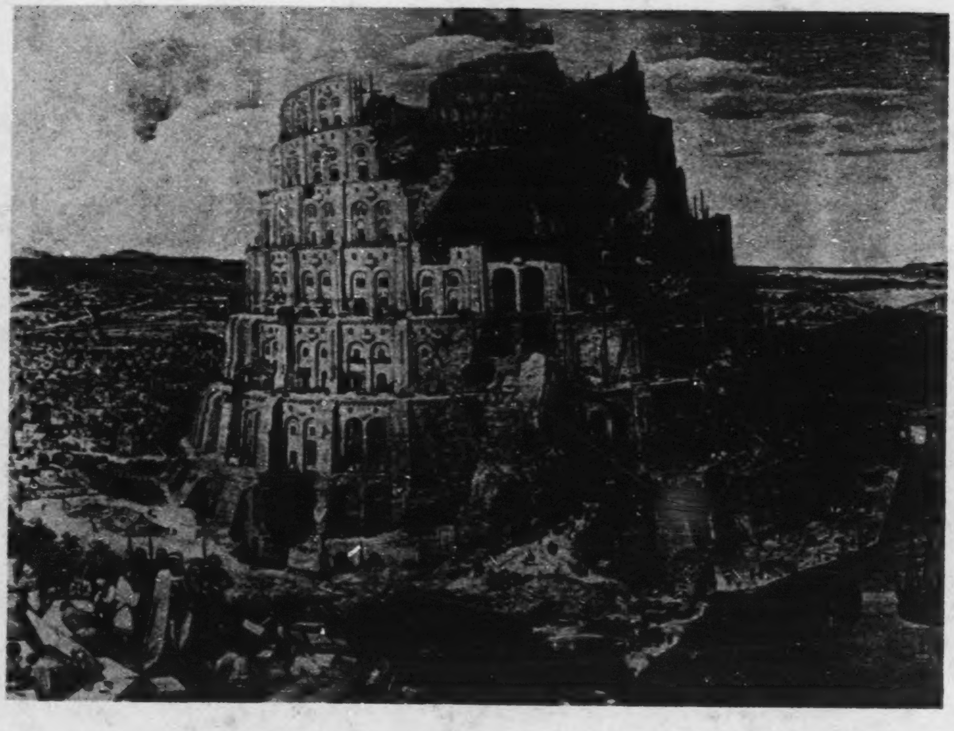
> our fascination with quarks, leptons, the forces of nature and their underlying symmetries are among the most "natural" (and hence most profound) activites in which humans engage themselves. A child asks questions: "Where does the sun go at night?" "What keeps the stars from falling down?" "How many words do I have inside of me?"
>
> It takes only a small amount of poetry to recognize these as questions wholly appropriate to high-energy physics (or molecular biology...). Nothing to fear—the child goes to school and



learns how to think "properly." He bends to organized constraints and grows up. He grows up to become a lawyer or policeman or doctor or sanitation worker. But some children don't grow up and they become high-energy physicists (or molecular biologists...).

The state of high-energy physics in 1983 is crystallized by the discovery, at CERN, of the W and Z bosons, putting the finishing touches to the Standard Picture. The Standard Picture is a snapshot of our understanding of the physical universe. This has three generations of quarks and leptons, and three gauge theories of forces, two of which are collected into the electroweak quantum field theory, carried by a family of gauge bosons: γ, Z^0, W^+, W^-. The Standard Picture encompasses and is in accord with all of the data that have been obtained in all of the world's particle physics laboratories. As such it is an intellectual edifice of monumental proportions. But the past five years have led to a growing consensus that the Standard Picture is a far from complete description of the physical universe.

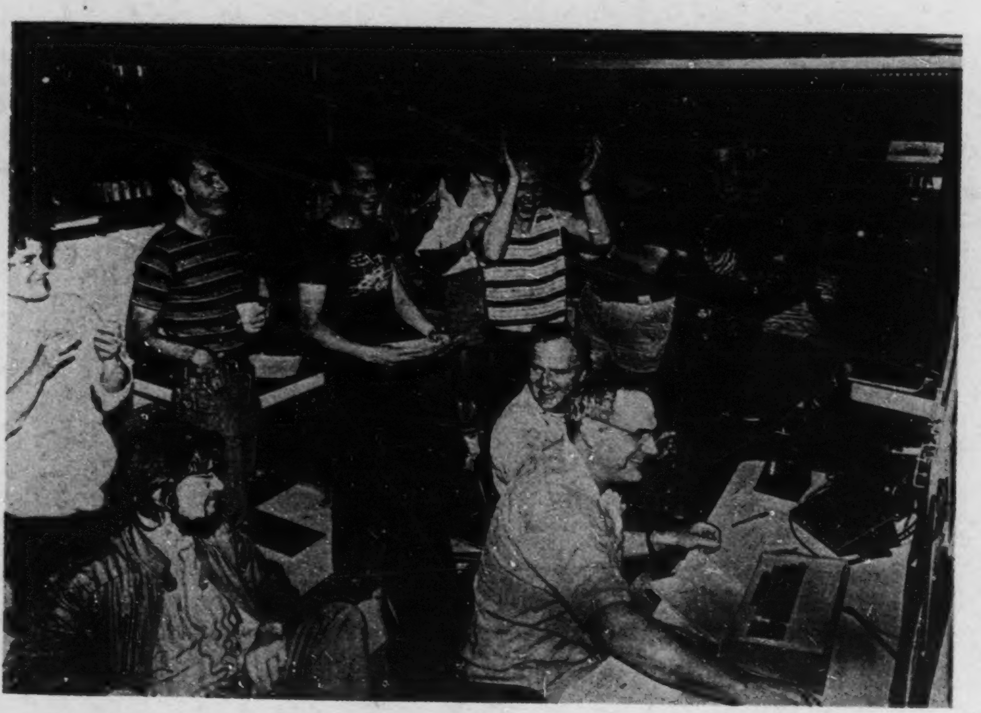
The limitations of the Standard Picture are in part illustrated by the difficulty of



incorporating the strong forces with the electroweak into a Grand Unified Theory and by the puzzling lack of conformity of the masses, for example, of the photon and the Z^0.

The situation may be compared to a group of mountain climbers, ascending the final slopes toward the summit. A long steep field is rapidly traversed and base camp (the Standard Picture) is made but the way seems to be blocked by a steep wall. For the past five years or so, all attempts to find a way up have failed. In our romantic metaphor, we know the summit is there, data provided by astrophysics from the early universe assure us of this and provide clues and constraints to the way up.

The task for physics is to continue to examine the domain of the Standard Picture—of ~ 100 GeV and less in the effective energy of point-like collisions. Surely the new physics beyond must leave tracks at lower energy. This involves precision and variety. We must look at hadron-hadron, lepton-lepton, and lepton-hadron collisions. We must examine the nature of the forces that bind quarks and the smallest corrections to the electroweak processes. A major contribution



The Control Room on Sunday, July 3, at 3:37 p.m. as the Energy Saver reached its primary design goal and accelerated protons to 512 GeV, a new world record for accelerators. This photograph also appears on the cover of this report.

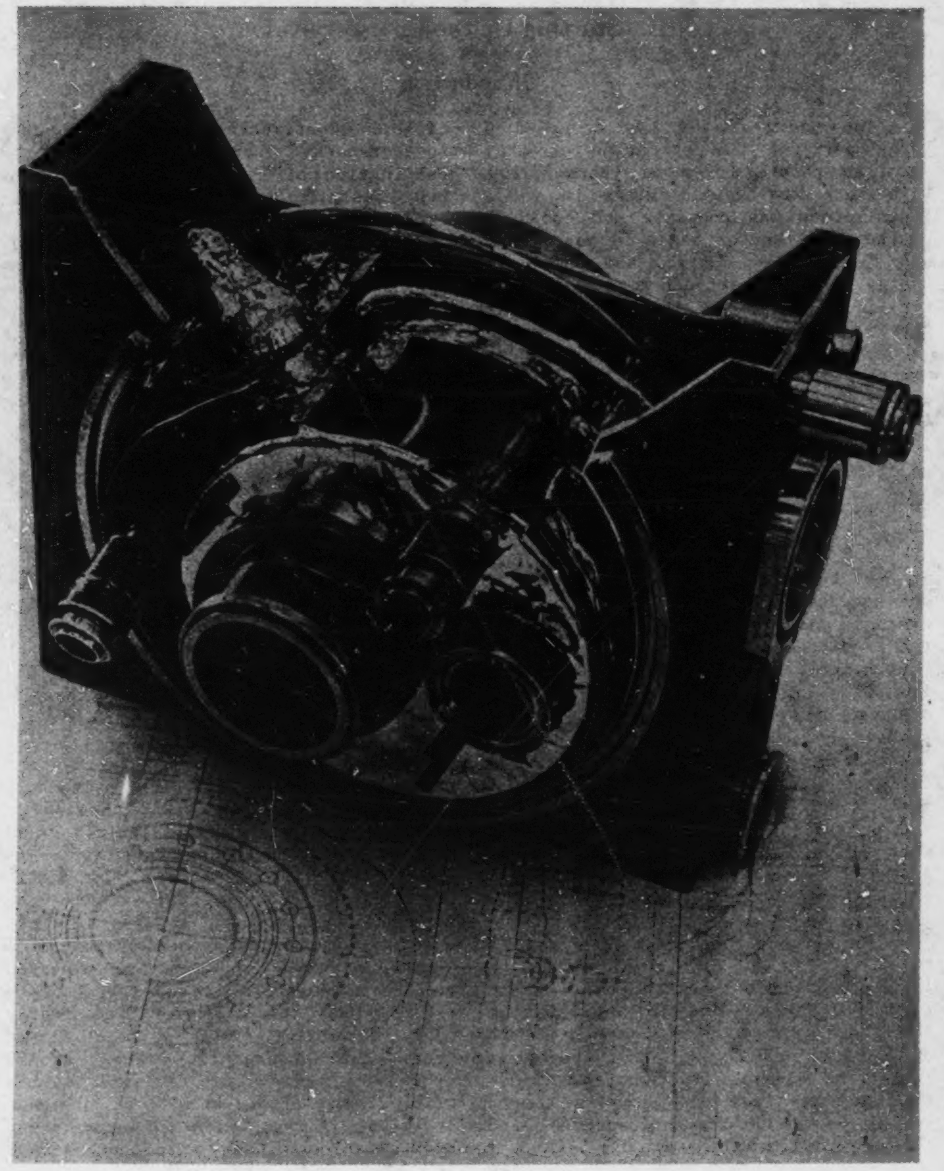
CDC
GEV
400
EV1

to this search will be the Tevatron's fixed-target program (TeV II) with secondary and tertiary beams of protons, neutrons, pions, kaons, hyperons, photons, muons, and neutrinos. This effort will be greatly aided by the SLC e^+e^- collider at SLAC and the similar effort at CERN, LEP. Data from Cornell's CESR, from LEP and Brookhaven's AGS will also contribute.

And of course we must continue to raise the energy beyond the W, Z domain--to look for handholds and crevices which will lead to the summit. Tevatron I, the collisions of protons and antiprotons at 2 TeV, effectively 400 GeV of point-like collision energy, will be the first look there. Ultimately, from what we can now perceive of the size and height of the wall, we will need much more energy. Only when we can go **beyond** 1 TeV in point-like energy--at least 20 TeV in the c.m. for hadron colliders, can we be sure that the wall we do see can be overcome.

I ended with the remark that there must be something fine and admirable about an institution whose firm, unwavering five year plan is revised so frequently.

Leon M Lederman



II. Starting Up the Energy Saver

Introduction

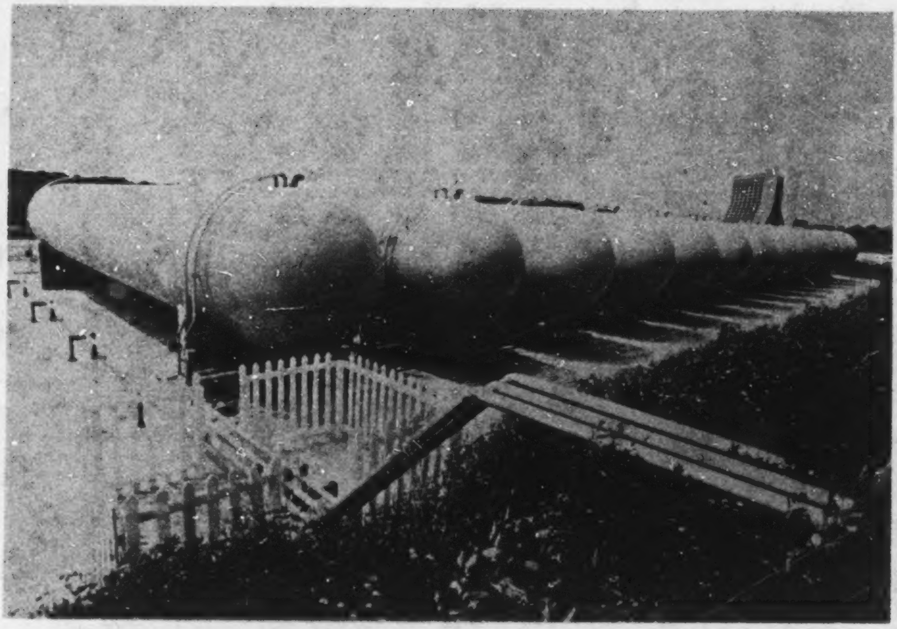
The Energy Saver has occupied a large part of the attention of many Fermilab people for some years. All this work reached a climax in 1983. Installation was complete and cooldown of the final sector began in May. Beam was first injected into the completed Energy Saver Superconducting Accelerator on June 2, accelerated beam was first achieved on July 3, and resonant extracted beam first sent to the Beam Switchyard Area on August 2. A new energy record of 700 GeV was reached on August 12, during the 12th International Conference on High-Energy Accelerators. These events were the culmination of ten-and-a-half years of R&D, tests, construction, and installation of the new accelerator system in the Main-Ring tunnel. The final goal of a 800 to 1000 GeV proton beam at approximately 2 × 10^{13} ppp for fixed-target physics and $\bar{p}$-p storage and collision at $10^{30}\text{cm}^{-2}\text{sec}^{-1}$ awaits further tuneup and the construction of the $\bar{p}$ source (TeV I), but there is a story to tell of how we got to where we are.

What is Different in This Accelerator?

The use of superconducting magnets in a large accelerator brings with it the necessity for major new engineering systems and their control. Together the magnitudes of the overall amount of equipment, system complexity, and fragility of these new utility-like systems not only dwarf the corresponding components of the conventional accelerator, but also influence their design. The conventional components must also work effectively so that during early stages of commissioning, when overall reliability is not high, progress can be made toward obtaining an accelerated beam.

The superconducting magnets require a large cryogenic system to supply both liquid helium at 4.7 K and liquid nitrogen. The cryogenic system for the Energy Doubler provides 24 kW of cooling at 4.7 K. This system is larger by several orders of magnitude than any previous one and its smooth operation is a major advance and triumph for its builders.

The Energy Saver magnets require an "active" quench protection system in order that the magnet conductor is not damaged by overheating when a magnet goes normal and "quenches." The active protection system continuously monitors voltage across the magnet cells at about 250 points and detects any resistive component greater than a given threshold. Upon quench detection, three things happen: a) Stainless-steel strips in the magnets adjacent to the coil are heated by discharging capacitors into them, thus causing uniform energy absorption in the quenched cell and reducing overheating at isolated spots; b) The main bus current is diverted around the quenched cell through a bypass circuit external to the cryogenic system; c) The main power supplies are bypassed and dump resistors are switched in to extract the total ring stored energy (350 MJ at 1000 TeV) with a 12-sec decay time constant. The quench-protection system is a ring-wide system with 24 microprocessors (one in each service building) which are in constant communication with one another. Each is constantly checking the voltage reading from its part of the magnet string. Any missed communication or

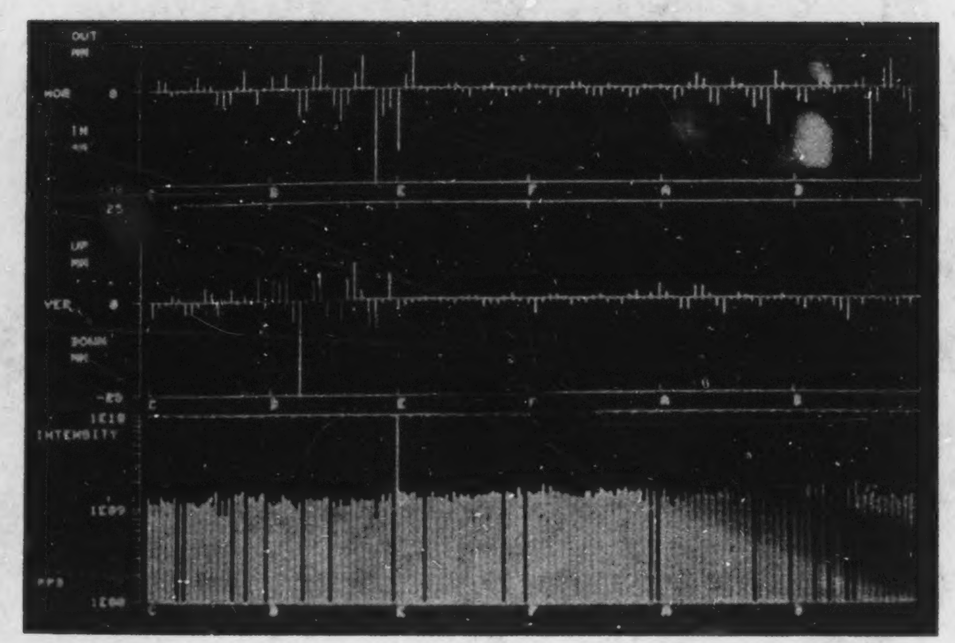


Helium storage tanks of the Energy Saver.

noise can potentially turn off the magnet power system or quench the magnet accidentally.

The vacuum system for the superconducting magnets is much more complicated than for a standard accelerator. The system consists of an outer insulating vacuum jacket with four isolated inner volumes, each of which must be leak-tight to the insulating vacuum. These volumes are a) the bore-tube high-vacuum region in which the beam runs; b) the single-phase helium space; c) the two-phase helium space; d) the nitrogen-shield space. Not only must one provide pumps and instrumentation for the two separate vacuum systems, but during installation, leak checking must be performed on the four separate internal volumes where the flange joints are not externally available for classical leak-check procedures. One potential advantage is that the beam vacuum bore tube is at low temperature and automatically provides very low pressure.

Because of worry about the feasibility of the operation of the cryogenic system, the quench-protection system, and the vacuum system, special efforts were made early on in order to develop workable engineering plans, both for implementing the systems and for successful installation procedures. Very substantial efforts were required from the electrical enginering and controls groups in order to meet the demands of the "utility systems" on a



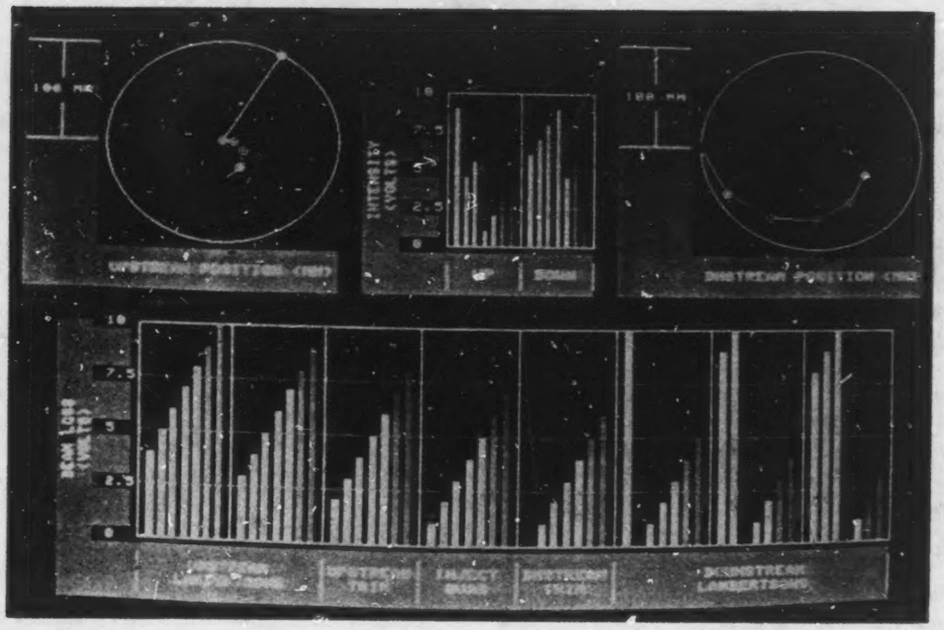
First complete turn around the Energy Saver: 5:42 p.m., June 2, 1983. The top two signals are horizontal and vertical beam positions around the ring. The bottom signal is intensity.

timescale that allowed for test debugging and refinement of techinques before the scheduled start of beam operation.

Superconducting magnets are sensitive to beam loss and have magnetic-field characteristics different from conventional iron magnets. Within the conventional accelerator systems, particular attention has been given to the correction and adjustment coil system and to the beam-position and loss-monitor systems.

The beam-position and loss-monitor systems were planned with the view that one wanted to obtain the most information possible from a single shot of injected beam. If the magnets quenched because of the beam being mis-steered, corrective action could be taken during the quench-recovery time (typically, 10 minutes to 2 hours) and the beam could get further on the next pulse. Special attention was also given to being able to run at very low intensity (10^{10}p) so as to reduce the magnet-quench probability. Thus the system was required to be very sensitive and at the same time very flexible, because it must be able to gather and store one-turn information and closed-orbit information at many positions and times through the cycle.

The one-turn position information, coupled with the one-turn abort system, and beam-loss information proved to be very effective in locating obstacles in


100 MM
UPSTREAM POSITION (MM)
10
7.5
INTENSITY (VOLTS)
2.5
0
UP
DOWN
100 MM
DNSTREAM POSITION (MM)
10
7.5
BEAM LOSS (VOLTS)
5
2.5
0
UPSTREAM TRIM
INJECT
DNSTREAM TRIM
DOWNSTREAM LAMBERTSONS

Control Room display of orbit position and beam loss during injection.

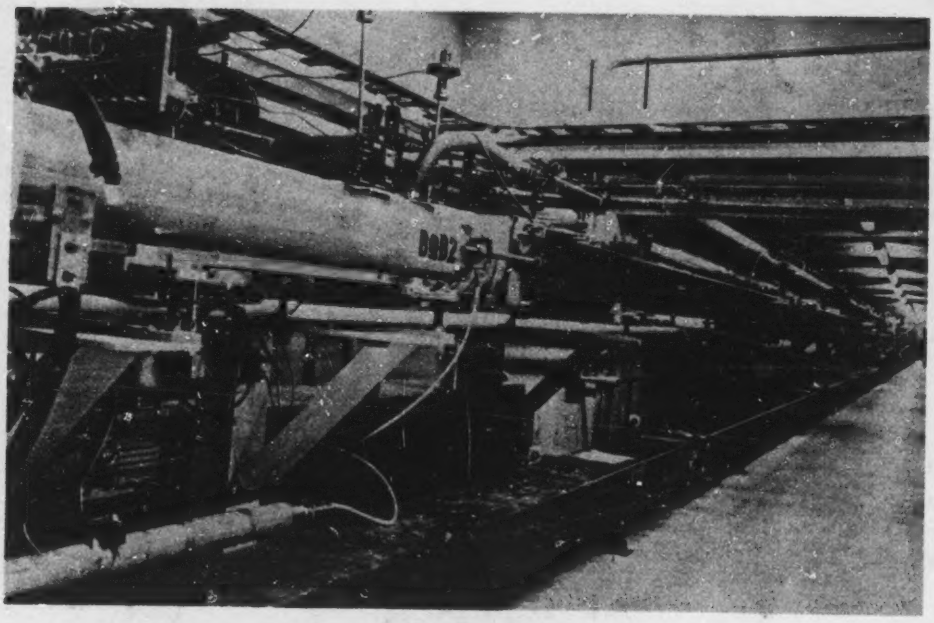
the aperture and in obtaining correct injection conditions, including guide field setting. The one-turn and closed-orbit information can be relayed to a program that determines dipole correction-coil adjustments. As it turned out, the closed orbit did not change appreciably with excitation, making the problem of accelerating to higher and higher energies less arduous than expected. The ability to abort the beam on loss has been of substantial use in trying to go to higher intensities, especially during extraction studies. The turn-by-turn position information has been of great value, not only at injection time for minimizing coherent oscillations, but also for minimizing injection guide-field mismatch and for doing tune measurements at any excitation with a "pinger" to induce coherent betatron oscillations.

The correction-coil system is composed of corrections and adjustments for steering, tune and chromaticity control, and resonant-extraction control. The system allows for programming control of all circuits from injection to full excitation. It is desirable to be able to center the beam accurately with dipole corrections at any excitation, thus making full use of the available aperture. This is particularly true at extraction time, when the resonant beam is making large excursions. The system allows for any unexpected shift or rotation of the main magnets with excitation, quench,

Vacuum work on the Energy Saver.

or upon a warm-up/cool-down cycle, without recourse to magnet realignment, which would be somewhat risky to the vacuum integrity. Although the initial magnet-survey alignment and stability of the superconducting magnets so far seem good, the advantages of the full-excitation corrections in operational convenience seem well worth the expense in this machine and in any future large accelerator where strength of superconducting correction is not a problem.

Here again the control system plays an essential role in the success of these sophisticated correction and detection systems. Extensive use of microprocessors to provide local control-curve generation and data storage has been a fundamental feature of these systems.

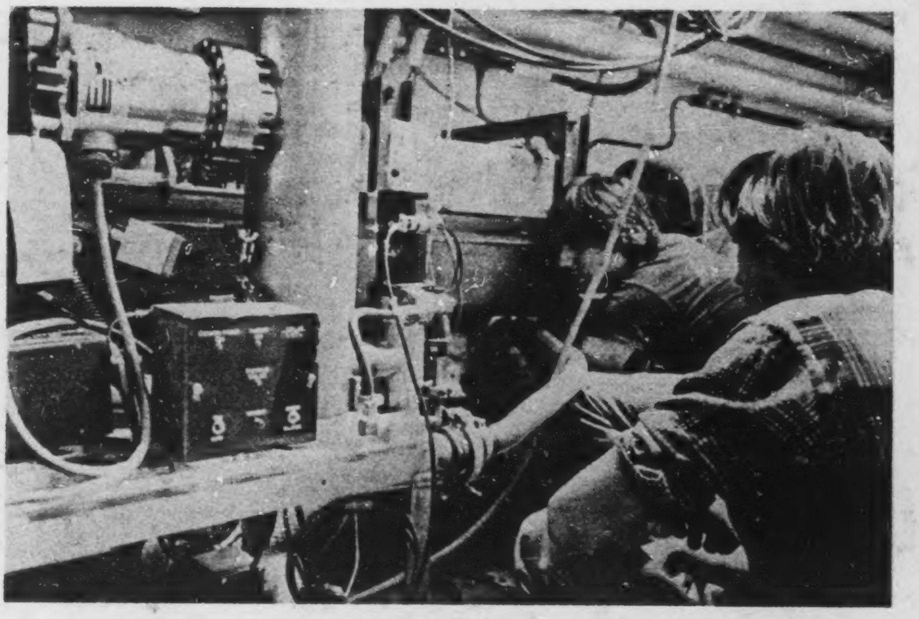


B12 test area.

Magnet String History

The importance of the test efforts carried out during the Energy Saver R & D and Construction Phase cannot be emphasized enough. These test efforts included: 1) vertical dewar tests of short magnets and cable in order to measure quench propagation, to conquer coil motion, training and quench current restrictions of the basic coil package; 2) both room-temperature and cold magnetic measurements to obtain and maintain the necessary field quality and reproducibility during prototyping and construction; 3) the establishment of the B12 test area (an above-ground magnet string test area located near station B12 of the Main Ring tunnel), and finally 4) tunnel system testing in A Sector.

The B12 test area was where installation and vacuum problems were first addressed, then cryogenic operation, then quench propagation in the magnet-string environment. Quench-protection, power supply, vacuum, refrigeration, and control systems prototyping were also done here. Tunnel tests were done on individual magnets, on strings of prototype magnets, and on the A Sector R&D final system. This progression from single-component tests to the final large integrated systems tests over the



Dave Augustine (front) and Wayne Hibbard connect vacuum pumping equipment.

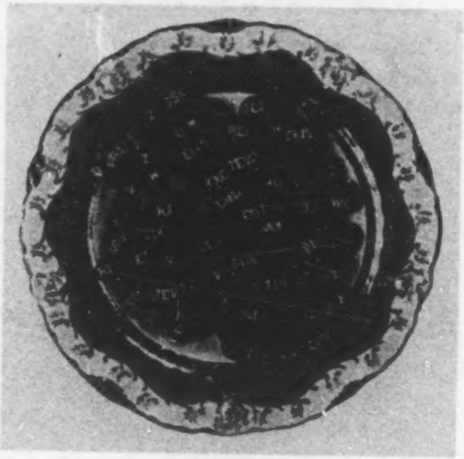
period of about nine years undoubtedly has been of paramount significance in the rapid turn-on and commissioning of the accelerator.

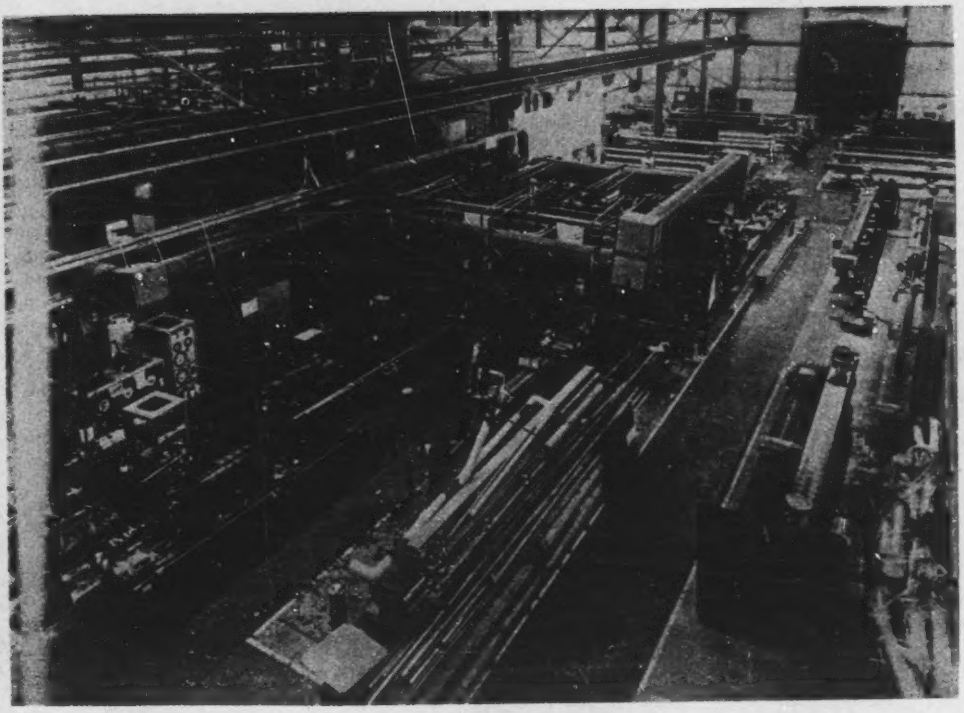
Talk about the idea of a superconducting magnet system started as early as September of 1970, but no serious discussions began until the fall of 1972, after the Main Ring had begun operation at 200 GeV for fixed-target experiments. Organized and committed R&D effort on the Energy Doubler began in the first part of 1973. By 1975, two tests had been carried out in which prototype magnets had been installed in the tunnel and beam transported through them. Not only were these installations basic milestones in the construction of cryogenic systems, but also they gave valuable data on the sensitivity of superconducting magnets to beam loss.

Early in 1976, the B12 test area was started with one 10-foot magnet. Tests continued until late spring of 1981, when the start of final installation in the tunnel took priority. The B12 area was reconfigured a number of times. It progressed to two 10-foot magnets, then two 22-foot magnets, then a four-dipole string which could not ramp above 2000 A because of an inadequate relief-valve system. The next configurations had two half cells of magnets, then four (one quad and four bends per half cell). The bends were still of the longer 22-foot variety. The final configuration had four half cells of the final ring-quality magnets and final correction-coil spools. A number of the configurations were changed when the tests terminated by the magnets blowing up.

Tunnel tests on magnet strings were carried out in two steps prior to the final ring installation shutdown. At the end of 1978, five half-cells of magnets were successully installed, made leak-tight, and cooled down. A 100-GeV beam was extracted from the Main Ring and transported through these magnets for 500 feet. Even though these magnets could not be ramped to appreciable excitation because of lack of quench-protection heaters, this was another important step in system development as well as a further test in transporting beam through magnets. One learned about how to survey the magnets (there were no correction coils), learned about quenches from injection errors, and to some extent, field stability after quench, and also tested the position-detector system.

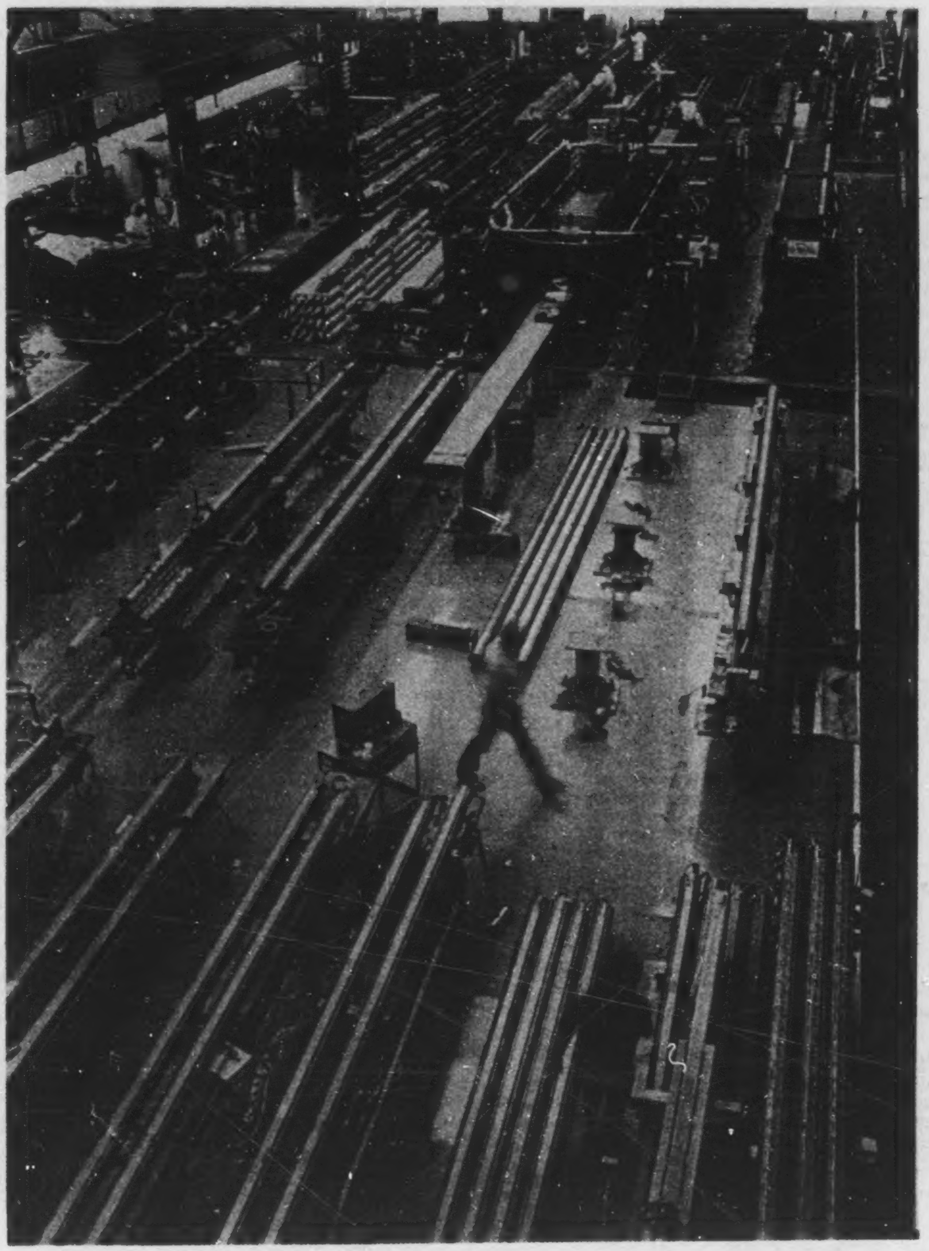
The most significant and final test program, "The 3/4 A-Sector Test" was carried out in the first half of 1982. It represented a full system test of 1/8 of the final ring components and controls. It tested to full potential all the cryogenic systems and pressure piping, the power-supply system and the quench-protection system. Extensive tests were performed to determine the possibility of voltage-to-ground breakdown of the electrical system during quench. The successful carrying out of the test was the final step in development of an overall system that would be reliable enough for operation when beam commissioning started about one year later.





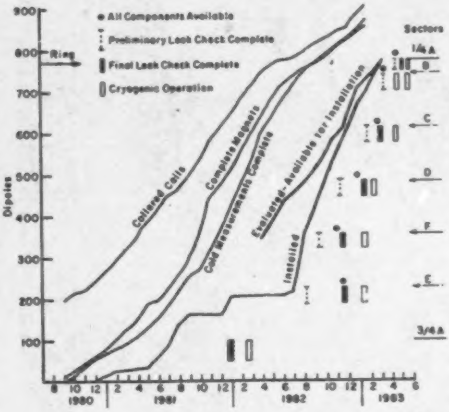
Magnet Test Facility.

Magnet Production Facility. Dipole coils are wound at the far end and completed collared coils are stored at the near end. →



Magnet Installation

The dipole production and installation time schedule is illustrated in the accompanying graph. It stretched over a four-year time period, beginning in the summer of 1979, when the decision to shorten the bend magnets from 22 feet to 21 feet was made in order to allow dedicated space for correction coils, instead of building them in the quadrupole magnet. The construction authorization for the project was given at this time and new shorter coils were soon available.



Dipole Production
and Ring Installation.

Availability of complete magnets lagged because of a movement problem found in the anchor system that ties the coil assembly to the outside of the cryostat. The learning curve is apparent both in the magnet production and in magnetic measurements. Coil production dropped off in 1982 because of problems in obtaining conductor. The gap between the curve of "measurement complete" and "available for installation" reflects not only the delay for paperwork between the time of measurement and the time at which the data became available, but also the need for a buffer from which to sort and select magnets to compensate for variations in field quality. It also reflects the fact that a number of magnets required rework in order to bring them up to the quality of the acceptance specification.

Initial installation proceeded during a shutdown in the summer of 1981, for a month at the end of 1981, and then the final installation started in June of 1982, with the last magnet going in the ring on March 18, 1983. Leak checking was first carried out on strings of four dipole magnets. Then quadrupoles and spoolpieces were installed for final leak check. Generally, special components were not quite ready when first needed, but did not hold up leak-check appreciably because of the option of moving and working in other sections of the tunnel.

Near the end of installation, the time delay between when magnets were first moved into A-Sector and when the string was finally cryogenically cold was six months.

Manpower for tunnel magnet installation, survey, flange hookup, and vacuum leak check took at peak about 54 people total. The total time period, counting work done in 1981, was about 15 months.

Handling damage during installation continued to be a problem throughout installation and many repairs were required in place in the tunnel.

Partway through installation a very high failure rate of the vacuum seals was experienced. This practically brought leak-checking progress to a stop. New types of seals reduced failures to an insignificant level.

There were worries that hipot of the magnets might be a problem, but no real difficulties were encountered during installation.

Specific failures that required warmup after initial cooldown, and remaining known faults are fortunately small enough to enumerate. Two cryosections (each 1/24 of ring) required warmup because of leaks and broken ceramics on correction leads. One dipole with a turn-to-turn short was found. (Later, when the collared coil was removed from the cryostat, the short disappeared.) Two splices of the power bus at interfaces were not soldered during installation. Six beam detectors near straight sections were in the wrong orientation (a universal accelerator problem) and five others had internally broken electrical connections out of over 200 units. Three correction magnets out of about 700 had low impedance to ground. Leaks in the insulating vacuum at eight locations required additional external pump carts to maintain sufficiently good vacuum.

Power Tests and Commissioning

Power-test commissioning history is given in the accompanying table. A total of 46 days over a four-month period were required (not counting the 3/4 A-Sector Test) to test the quench-protection system and ramp the magnets to 500-GeV excitation. During this time, the one magnet with a turn-to-turn short and two bad spliced joints were discovered. This fast turn-on did not allow much time for system reliablity to be hardened, as was reflected in later operation during beam tests.

Power Test 1983.

(660 A = 150 GeV)

E & F Sectors

2-22 ↓	500 A - 1 power supply. Quench bypass studies and power lead quenches.
3-3	2 kA
3-4 ↓ 4-15	Warm E-sector to repair vacuum leaks
4-15	4 power supply operation
4-22	Beam studies

C, D, E, & F Sectors

5-6	1 power supply
5-7	660 A
5-8	4 power supplies-can't ramp-bad dipole
5-11	Located bad dipole, C29-3

D, E, F, Sectors

5-12	660 A
5-14	2 kA

D, E, F, & A Sectors

5-25	900 A-Discover bad splice
5-26	Locate-A22

B, C, D, E, F, & A Sectors

5-31	220 A-Discover bad splice
6-1	Locate-B46-1
6-2	100 GeV beam studies
6-4 to 6-14	Repair A & B
6-15	Ramp to 400 GeV (1770 A)
6-16	Ramp to 500 GeV (2220 A)

Start beam tests

Beam Tests and Commissioning

A chronology of the beam tests and commissioning period is given in the accompanying table. The beam tests started April 22, 1983, with two weekends devoted to single-pass beam through E and F Sectors (one-third of the ring) before the full ring was completely installed and powered. Beam was transported through the two sectors within about 15 hours after first starting to inject. The major confusion during this exercise occurred because the first four out of five horizontal detectors were reversed in polarity (very few reversals were found in the rest of the ring). The rest of the time during these weekends was spent in testing the injection kicker (not required for a single pass), injecting into ramping magnets, and exercising a correction-dipole tuning program and exploring the aperture.

Beam was not injected again until June 2, when the ring was complete, but limited to 100-GeV excitation because of the bad bus splices. The correction-coil settings scaled from the April run were used in E and F Sectors and one turn of beam obtained within two hours of available beam time. The initial first-turn beam position data are shown in Figure 2. Beam is injected at the beginning of E Sector. Only a few steering corrections (approximately 6) were set in Sectors A, B, C, D.

An indication of up to 13 turns was obtained before turn-off two days later for warmup and repair of the bad bus splices. There was no real time-intensity signal available and the indication of turns came from the position detector turn-by-turn measurement-via the computer and perhaps was not the most credible of measurements.

Startup at 150-GeV injection began on June 17 with 150-GeV dc excitation. Up to 20-30 turns were obtained rather quickly but attenuation from turn to turn was severe. Over the next eight days, three aperture restrictions were found. The ability to look at single-turn beam positions and the ability to stop the beam after a fraction of a turn or after one-and-a-half turns, either by using the single turn extraction abort system, or by kicking the beam into straight sections using the strong dipole corrections, was of great help in finding these problems. There could be no confusion about losses from multiple turns. In the abort straight section C0, we found that an error had been made in the design of some beam pipe, severely limited the aperture. In the A0 extraction straight section, a wad of paper was found at a flange joint where it had been forgotten after modification of the pipe. At station E47 in a cryogenic region, an obstacle was detected which appeared to cover the lower half of the beam pipe. Beam could be steered around it without difficulty. Upon subsequent warmup of the region much later, nothing was found. Once the obstructions were corrected, coasting beam was easily obtained and the rf was turned on and acceleration checked by moving the radial beam position with the rf system.

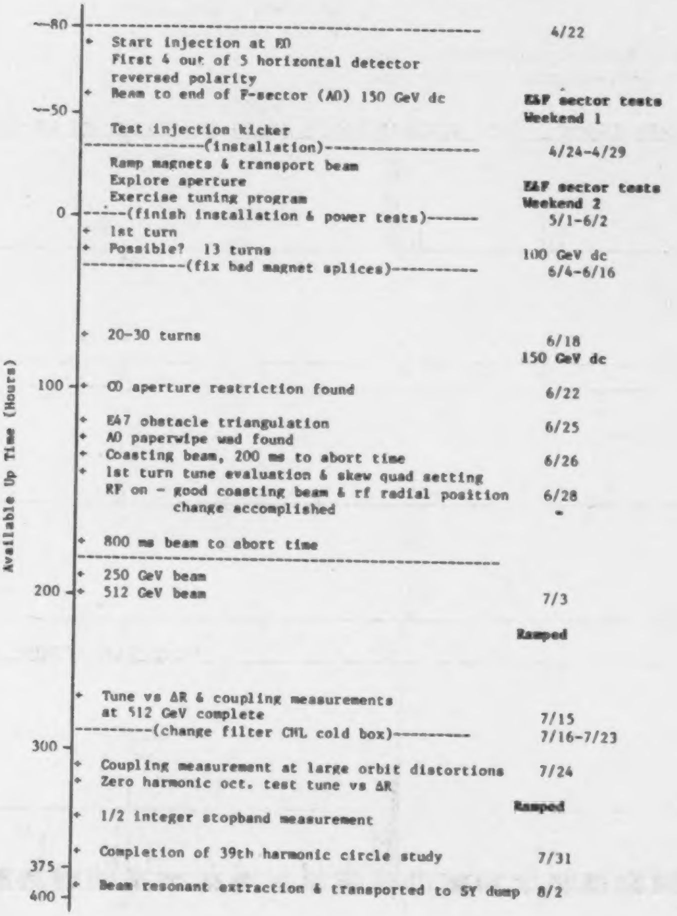
Once 0.8 sec of good beam to the abort time was established, ramped excitation, first to 250 GeV, then to 512 GeV, began. Beam accelerated with only minor difficulty. Dipole correction coils are automatically scaled with energy and needed little change with excitation.

Acceleration to 512 GeV was obtained on July 3, 1983, after about 210 hours of available system uptime and about 20 operating days from the start of full-ring operation.

After beam had been accelerated to 512 GeV, numerous measurements and adjustments at flat top were taken in order to prepare for resonant slow extraction. These measurements included: tune, tune vs. radial position (Δp/p), and horizontal-vertical coupling. Adjustments of the chromaticity and minimization of the coupling were performed. Higher-order correction magnets were tested and beam resonances explored.

These measurements took about three weeks (165 hours available uptime) with an interruption of one week downtime to change a clogged filter in the Central Helium Liquefier cold box. On August 2, 512-GeV beam was successfully resonantly extracted and transported to the beam dump in the beam switchyard area.

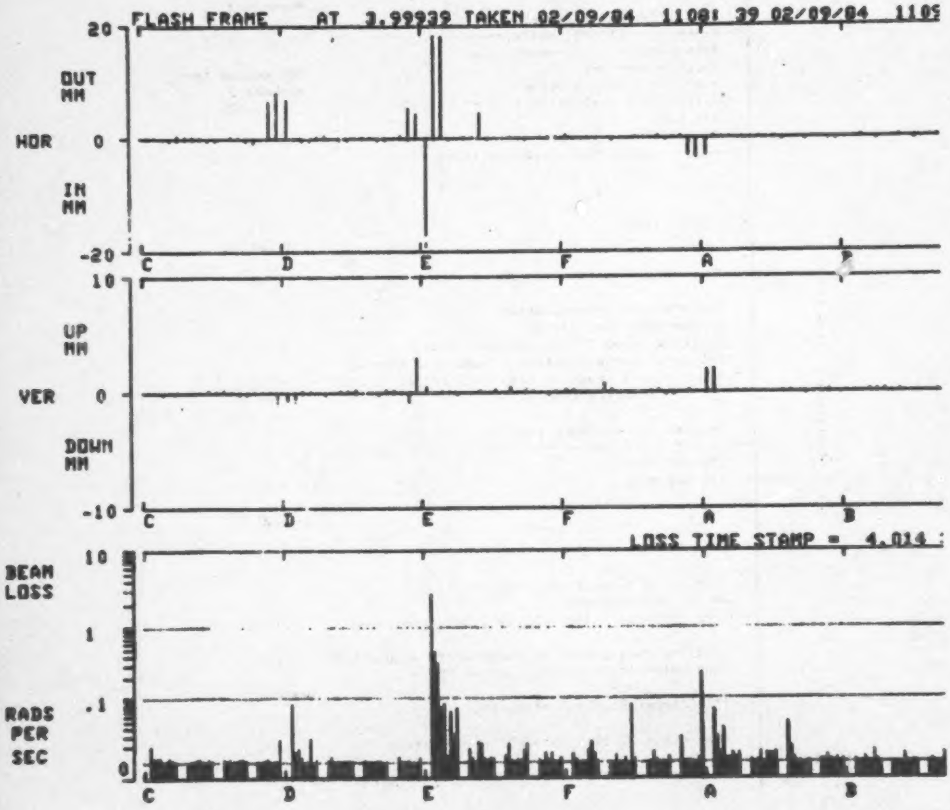
Beam Test and Commissioning.



Beam Measurements and Comparison with Magnetic Measurements

Orbit measurements have been carried out to a level of detail probably somewhat greater at this early stage than any previous accelerator. In addition, the magnetic fields of the magnets were measured before installation in equally great detail. It is therefore possible to compare the results of beam measurements with beam performance expected from the measured magnetic fields and some of this has been done.

There is general agreement, but also some inconsistencies between the two kinds of measurements. The beam measurements predict in several cases multipole errors in the magnetic fields that are larger than those measured. The reasons behind these discrepancies are not yet understood, and they are therefore puzzles, but it should be emphasized that these discrepancies are of the order of a few Gauss at 1-inch radius compared with a total peak field of 45,000 Gauss. At this level, the problems are interesting, but by no means crucial.

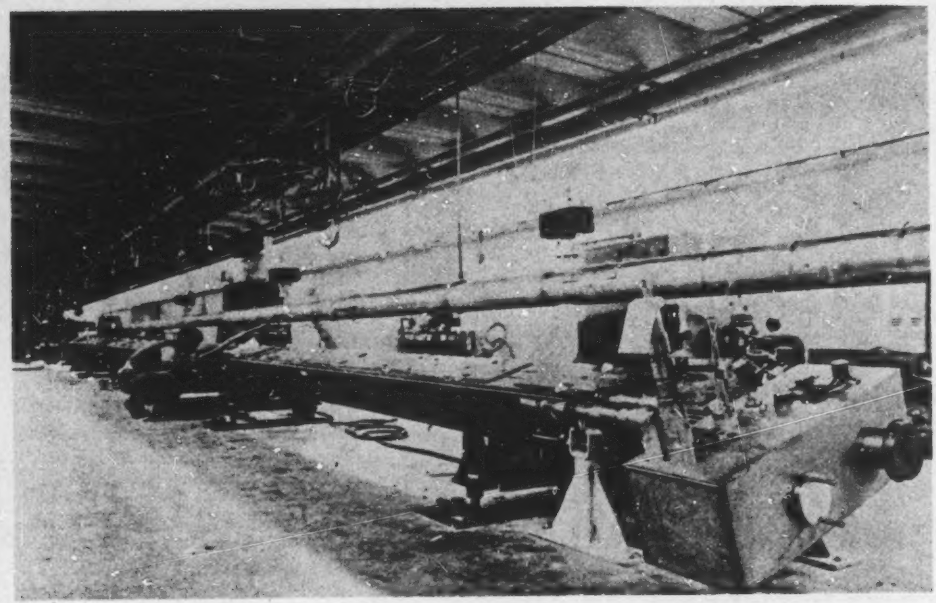


The completed Energy Saver.

Operational Experience and Reliability

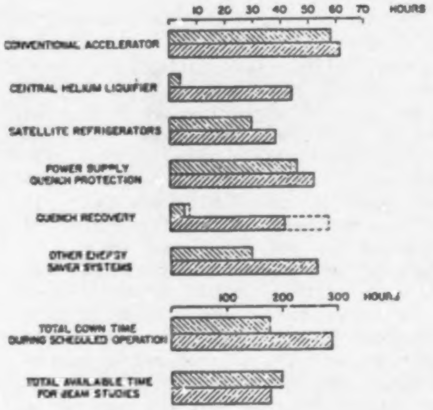
The reliability during the beam commissioning time was very poor, as can be seen by comparing the number of days it took for any phase with the amount of available uptime. (Available uptime is defined as any time when there was not recorded downtime. It does not reflect the inefficiencies of interruptions and confusion when controls do not seem to respond, for example.) Actual usable uptime seemed to the crews to be about half of what is indicated here. Whole shifts would go by with nothing productive accomplished. We have always planned on poor reliablity in initial operation and the data gathering of beam information was very effective in making efficient use of beam when it was available.

The accompanying graph illustrates the amount of downtime caused by various systems in the Energy Saver and caused by the conventional accelerator (Linac-Main Ring). Down-time increased substantially when ramping of the superconducting magnets was initiated and proper cooling required full Central Helium Liquefier output. Quench recovery, which was not a problem at 150-GeV dc operation, took considerably longer when quenches occurred at higher excitation. Failure of a number of devices could cause quenches that took much longer to



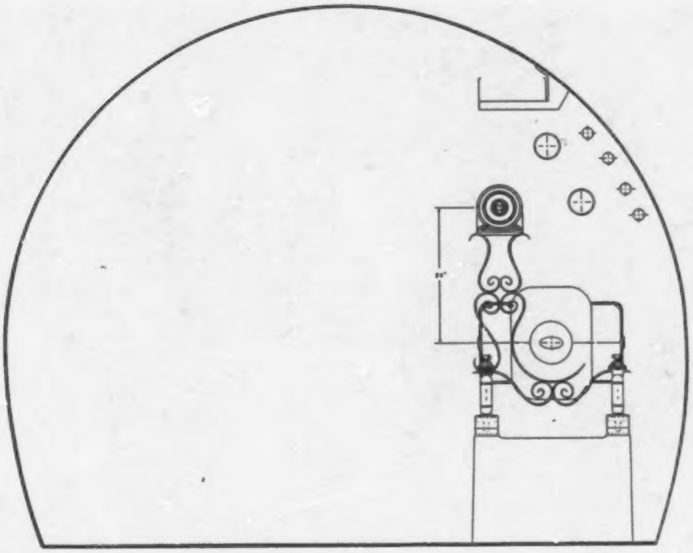
1-TeV beam extraction equipment at A0.

recover from than the adjustment or repair of the original problem. The refrigeration system was more reliable than expected, probably because of the reasonably long time (3 months) over half the system had been in operation before beam time. On the other hand, the power-supply quench-protection system had little operating time before beam startup.



DOWNTIME DURING SCHEDULED OPERATION
BY SYSTEM OR CATAGORY

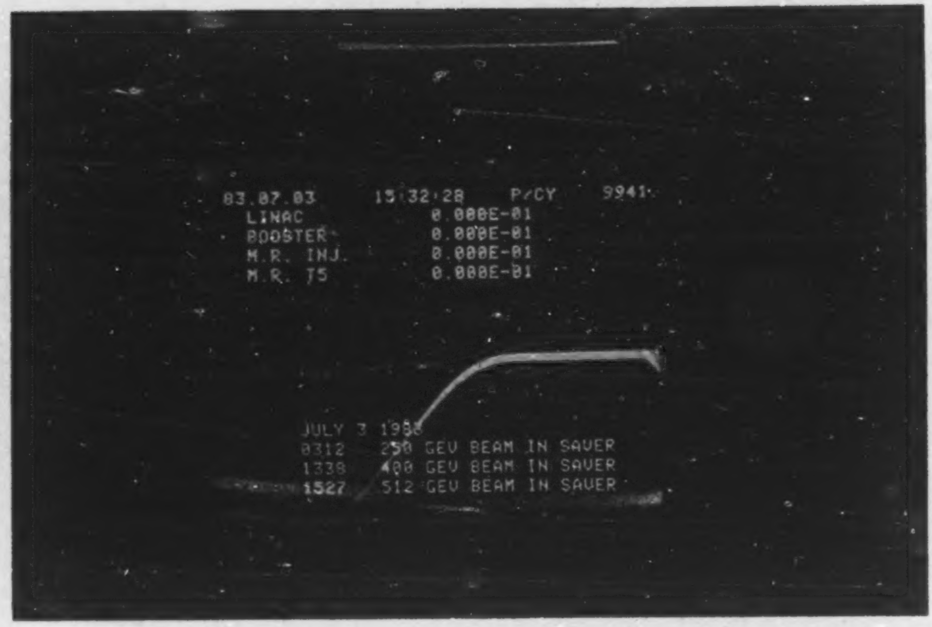
▧ 6/2/83 - 7/2/83 DC INJECTION EXCITATION
▨ 7/3/83 - 8/2/83 RAMPED (512 GeV) EXCITATION
☐ OTHER SYSTEM FAILURE LEADING TO QUENCH RECOVERY



One of the first designs for the Energy Saver with respect to its position in the Main-Ring tunnel.

Energy Saver Chronology

67-70	Discussions of adding superconducting magnets to ring.
3-71	RRW announces intention to request authorization to build Energy Doubler.
7-71	Carrigan suggests using Doubler for colliding beams (FN-233).
	FN-235 reports first small model quadrupole (Sheldon, Strauss).
9-72	Working group established.
1-73	R&D started.
4-73	First magnet tested.
5-73	First preliminary design report (TM-421).
1-74	Energy Doubler Design Study Progress Report.
5-75	Beam transported through one 3-ft magnet at B12. Magnet hung on tunnel ceiling.
7-75	Central Helium Liquefier Satellite concept developed.
8-75	Beam quench studies on early superconducting magnet in A0 extraction line.



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83.07.03      15:32:28     P/CY     9941
  LINAC               0.000E-01
  BOOSTER             0.000E-01
  M.R. INJ.           0.000E-01
  M.R. T5             0.000E-01

        JULY 3 1983
        0312   250 GEV BEAM IN SAVER
        1338   400 GEV BEAM IN SAVER
        1527   512 GEV BEAM IN SAVER
```

Energy Saver Chronology

12-75	External collar concept developed.
2-76	B12 above-ground test area started.
1976	About ten 22-ft magnets made.
1977	B12 test area-four magnet string test started < 2000 A.
12-78	Beam transported A0 to A17, 22-ft magnet (20 dipoles, 3 quads).
5-79	Final design report-change magnet design length to 21 ft.
6-79	B12 test area-16 22-ft magnets, 4 quads installed.
7-79	Start of construction.
12-80	Start installation of A-sector.
1-81	B12 test area-16 21-ft magnets, 4 quads, installation starts.
3-81	B12 test area-start tests on final magnets.
5-81 12-81	Installation of 3/4 A-sector.

Leon Lederman and Linda Klamp celebrate 512 GeV.

Energy Saver Chronology

1-82 6-82	3/4 A-sector test to 4200 A	Cryogenics Power Voltage-to-ground Quench Protection Pressure Tests
6-82	400 GeV program terminated.	
3-83	Magnet installation complete.	
5-83	Entire accelerator cooled to liquid helium.	
6-2-83	First full turn.	
6-26-83	Many turns: coasting beam.	
7-3-83	Beam accelerated to 512 GeV.	
8-2-83	Extraction to Experimental Areas.	
8-15-83	Beam accelerated to 700 GeV.	
10-1-83	Experimental program starts.	
1-10-83	Beam physics program; storage for over 30 hours.	

Conclusion

The Energy Doubler gives every indication of being a very stable, rational accelerator with no particular aperture problem and with classical optical properties. It still must get to design intensity and energy. Problems that occurred during installation and commissioning were sufficiently small as to allow enumeration. None seem fundamental at this time. The long, careful test program was probably instrumental in making for a rather rapid turn-on period.

On August 15, 1983, beam was accelerated to 700 GeV and on August 19, a test of the controls for beam storage was attempted. Beam was held for about 13 minutes before being aborted on command. Beam attenuation during this time was less than 3-4%, even though all 12 power supplies were on and no attempt was made to select any particular tune value. The major technical goals of a superconducting accelerator have been achieved.

The conception of the Energy Doubler is due to the imagination, determination, and foresight of R. R. Wilson. The success of the magnet program has its foundation in the work of Alvin Tollestrup. The environment for success has been generated under the direction of Leon Lederman who made this project the number one priority of the Laboratory.

The professionalism, desire for excellence, and commitment of the Fermilab employees to schedule and performance have brought this project to realization.

Helen T Edwards

近藤、宮下様

本日、三品さんと福井君と僕の3人で、glueing 及び gas vessel への assembly について議論した結果を報告します。

1. 位置決めの精度

a) pattern の位置決めの精度は ±1mm であること。

b) 90°の直線は、ケガキ線の外へはみ出すとしても +0.5mm 以下であること。

c) 内側の円弧の部分は本来の位置より 1.3mm 以上でてはいけない。

以上の a) b) c) の規格のうち、c)は a)が満たされれば自動的に満たされる。

2. Glueing（4頁目の絵を参考にして下さい。）

鉛とチェンバーとの貼り合わせは、以下の手順で行ないます。

a) チェンバーの45°の30mmφ穴の部分に真ちゅうのスペーサーを入れ、ロッドに通す。ロッドの直径は 28mm で、スペーサーに開いた穴は直径 28.1mm です。glue を塗った後、鉛板をロッドに通す。これを4回（あるいは5回）繰返す。

鉛板の上に glue を塗る。

III. CDF, The Collider Detector at Fermilab

Introduction

By now, almost everyone who visits or works at Fermilab has passed by the large orange building on Road D between Batavia Road and the Central Laboratory. This building, known as the B0 Collision Hall and Assembly Area, is the home for a large experiment being built to measure what happens when beams of protons and antiprotons, counter-rotating in the Tevatron, collide head-on.

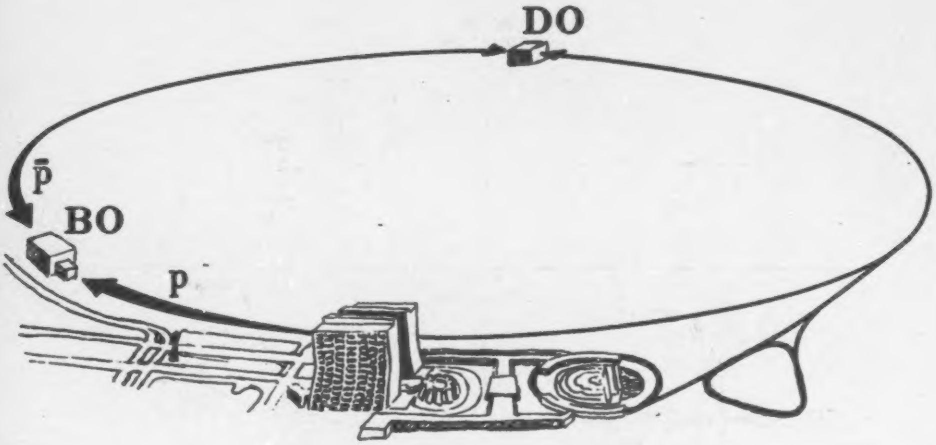
The apparatus for this experiment is called CDF, the Collider Detector at Fermilab. When experiments using CDF begin in 1985-1986, they will be observing the highest-energy collisions ever produced in a laboratory, some three to four times the highest available now at the CERN laboratory in Geneva, Switzerland. These very high energies allow physicists to probe much deeper into the structure of matter than heretofore possible. We are not sure what will be found with CDF--that is the excitement of high-energy physics--but we do know that it will make significant contributions to our knowledge of the subnuclear world where current understanding is incomplete.

This article will look at some of the kinds of physics questions that can be addressed by a detector such as CDF; these considerations are what led to the basic design of CDF. The hardware being constructed for CDF will be described. Finally, some of the plans for using CDF will be mentioned.

A major high-energy physics enterprise such as this one is really a form of high adventure, much like the Spanish voyages of discovery or an Himalayan climbing expedition. To succeed, these enterprises demand the talent, dedication, and hard work of a large number of individuals. In the case of CDF, physicists and secretaries, engineers and technicians, draftsmen and machinists, students and business managers are all part of the enterprise. All told, there are 200 people all over the world working directly on CDF. They come from ten U.S. universities (Brandeis, Chicago, Harvard, Illinois, Pennsylvania, Purdue, Rockefeller, Rutgers, Texas A&M, and Wisconsin), three U.S. national laboratories (Argonne, Fermilab, and Lawrence Berkeley) and two foreign countries, Italy (Italy--University of Pisa and Frascati National Laboratory) and Japan (Japan--KEK National Laboratory for High Energy Physics, Fukui University, Saga University, and Tsukuba University).

Like other great adventures, CDF also needs its ships and supplies. The major funding for CDF comes from the U.S. Department of Energy. The DOE equipment funds are managed by the CDF Department at Fermilab and are distributed to the U.S. university and laboratory groups. The U.S. National Science Foundation supports CDF principally through two of the collaborating university groups. The second largest source of funds for CDF is the Japanese Ministry of Education through the joint U.S./Japan Accord program for high-energy physics. The Japanese MOE also provided important support for the superconducting solenoid coil through a special program with Tsukuba University. Significant support for CDF is being provided by the Italian government through INFN.

Another essential ingredient in the experiments planned for CDF is the source of antiprotons being built by the Tevatron I group at Fermilab. This is an extremely challenging and interesting project in its own right, but space does not permit an adequate description here. It will simply be assumed that the antiproton source provides intense bunches of antiprotons



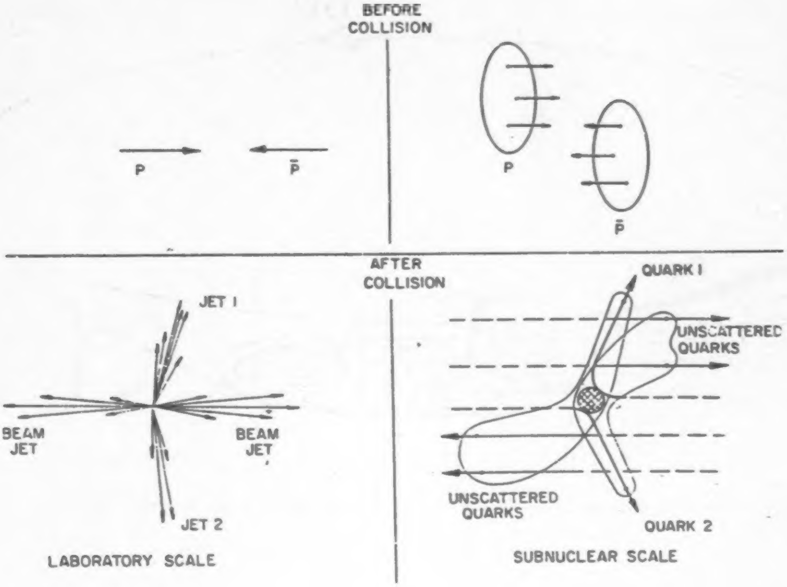
The Fermilab ring and the collision points at BO and DO.

that are stored and circulate in the Tevatron. Since antiprotons have the opposite electric charge as protons, they will circulate in the opposite direction to protons, but on the same path. Both the protons and antiprotons will be confined to sausage-like bunches, approximately 1 meter long and less than a millimeter in diameter. It is expected that there will be three such bunches of protons and three bunches of antiprotons, each set being equally spaced around the Tevatron. There they travel at very nearly the speed of light for periods of several hours while the experiments are in progress. Collisions between the bunches of protons and antiprotons will actually take place at six points around the Tevatron. CDF will observe the collisions that take place in the BO straight section; another experiment now just beginning to be organized will operate at a second region called DO.

No attempt will be made here to identify all of the specific contributions being made to CDF by individuals or collaborating institutions; this is simply too large a task. The problem of coordinating the construction of complicated detector components that are being built all over the world is an interesting one, however, and some of these coordinating efforts will be described.

Physics

The past fifteen years have been a revolutionary period in the understanding of the basic constituents of matter and the forces between them. Physicists immodestly include everything in the universe when they talk about matter. Their hope is to gain an understanding of all the diverse behavior of all the matter around us by trying to break matter into smaller and smaller



pieces and discovering the force laws that govern the interactions of all the pieces. It is very much an open question whether this process will ever end, but most physicists would like to find a basic or fundamental set of building blocks out of which everything is made.

The essential fact that has emerged over the past few years is that all matter is made out of just two classes of elementary building blocks or constituents. The particles that make up one of the classes are called "quarks"; members of the second class go by the name of "leptons." For each quark or lepton, there is a kind of mirror partner known as an antiquark or antilepton. The antimatter that is made from antiquarks and antileptons is not found under normal conditions, but it is routinely produced at high-energy particle accelerators such as Fermilab.

Five different kinds of quarks are now known; most physicists fully expect that a sixth will be found in the relatively near future. The main reason behind this confidence is that six leptons are also known to exist and there are deep reasons to believe the two families of particles may have exactly the same number of members.

The great achievement of the past 20 years has been the realization that quarks are the basic building blocks of atomic nuclei, even though they appear to be so tightly bound into nuclei that individual quarks have never been broken free and isolated in the laboratory. Nevertheless, by scattering particles off nuclei and other kinds of high-energy physics experiments, the picture of the internal structure provided by the quarks has become incontrovertible. Quarks are bound into nuclei and other subatomic particles by

Hans Jensen

Dennis Theriot

objects called gluons. These are the carriers of the strong nuclear force.

The most familiar lepton is the electron. Electrons orbit around nuclei to form atoms and molecules. They are largely responsible for the chemical properties of ordinary matter and for electrical conduction.

It is interesting to note that essentially all matter normally encountered on earth is composed of only the two lightest quarks and involves interactions with only two of the six known leptons. To paraphrase a well-known physicist, when this question first arose, "Who ordered all the others?!."

With so many different kinds of quarks and leptons, a natural question is whether all these objects are themselves made out of even smaller, more fundamental building blocks. As yet, there is no experimental evidence for such things, but they will certainly be sought in the Tevatron experiments.

The basic strategy in the CDF experiments on the Tevatron is to see what happens when quarks and antiquarks collide at very high energies. Because it is impossible to make beams of quarks, we plan to use the quarks that are normally bound in protons (the nucleus of hydrogen) and collide them with the antiquarks in antiprotons. Of course, what is actually done is to collide beams of protons and antiprotons that are stored in the Tevatron, circulating in opposite directions.

Most of the time, the protons and antiprotons will miss, but on rare occasion, the two beam particles will pass so close to one another that a quark in the proton will have a very violent collision with an antiquark in the antiproton. When that happens, various results are possible. In the simplest case, the quark and antiquark will bounce off one another much like billiard balls. If they scatter at large angles from the original beam direction, the quark and antiquark "billiard balls" will move away from their companion quarks in the original proton and antiproton.

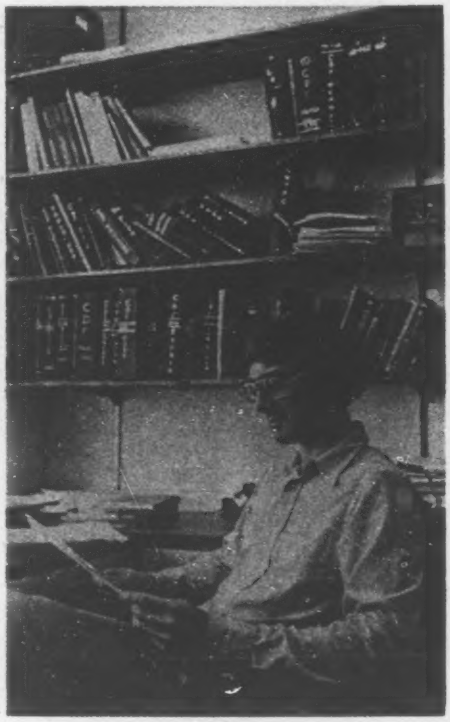
The gluons that bind quarks in nuclei prevent the quarks from traveling too far (about the diameter of a proton or roughly 10^{-13}cm) before they are transformed into a narrow cluster of several energetic subatomic particles, built out of more quarks and antiquarks. These clusters are called "jets"; the particles in jets are the objects actually observed in experiments such as CDF. The gluons can also collide with quarks or other gluons, giving rise to jets very similar to the quark jets.

The other quarks in the original proton that did not collide continue in the beam direction and also are manifested as jets of subatomic particles. These are called "beam jets"; they usually travel along the original beam direction and are ignored as much as possible in experiments. A schematic representation of this quark-antiquark collision process is shown on page 61.

A billiard ball-like collision is not the only thing that can happen; the other possibilities are what make these experiments so interesting. For example, in the recent experiments at the CERN collider, it was found that occasionally the collision energy was transformed into new kinds of particles, called W and Z bosons. These particles were then observed to decay into leptons which were detected in the experiments. The original quark and antiquark actually disappeared to make the new particles. This was the first time W and Z particles had been seen and their observation provided a crucial confirmation of the theory of the forces between leptons and quarks, which predicted the existence of the new particles.

The CERN experiments succeeded in

Roy Schwitters



Bob Kephart

Hans Kautzky

Cathy van Ingen

finding the W and Z particles because of the very high collision energy provided by their proton-antiproton collider. No other existing accelerators could produce such high masses. The Fermilab Tevatron collider can reach energies several times higher than CERN, which puts it in position to find even higher-mass particles if they exist. The goal for CDF is to detect jets and leptons coming from collisions in the Tevatron and infer whether they arise from billiard-like collisions, W or Z particles, new and heavier particles, or completely new, unexpected phenomena.

The Detector

Given these physics goals, the challenge to the detector builders is to find practical ways to observe all of the particles created in the proton-antiproton collisions, the jets and lepton, and to interpret these in terms of the underlying quarks, leptons, and new particles such as the W's and Z's.

An isometric drawing of CDF is shown on page 70. CDF consists of a 2000-ton central detector surrounding the intersection region of the beams, and two large forward/backward detectors to measure particles produced at small angles with respect to the beam direction. Not shown in the figure is a complex system of special electronics and computers that collect and process information from the detectors yielding digital "images" of the collision events that can be studied by physicists. What are all the parts of CDF and how do they work?

The essential fact that is exploited by all detectors in high-energy physics is that when charged particles pass through matter, they ionize atoms along their path. By detecting the ionization, we can follow the particle much like a high-flying jet airplane can be followed by its vapor trail even though one cannot actually see the aircraft. This ionization is measured in several ways. In certain gases, the electrons liberated by ionization of the gas can be collected on wires and amplified by sensitive electronic circuits. The position of the wires and the electric charge collected then tell where the particle went and how much ionization it left behind. In plastic materials doped with special chemicals, the ionization produces small flashes of light that are detected by sensitive photomultiplier tubes that convert the light to electrical impulses.

Different kinds of particles interact differently when they pass through matter. One of the leptons, the muon, has essentially no interactions except for ionization and is capable of penetrating great distances through heavy materials such as steel. High-energy electrons interact in a few millimeters in heavy materials such as lead, giving rise to what is called a shower of more electrons and their antiparticles, called positrons. By the time the shower penetrates several centimeters of lead, essentially all of the energy of the original electron is converted into hundreds or thousands of particles in the shower and the shower dies out.

Masa Mishina

The particles that make up jets, collectively known as hadrons, have interactions in ordinary matter somewhat intermediate between muons and electrons. They can travel several centimeters through iron or lead before new particles are created and a shower starts to form. The shower tends to stretch out over a meter or so of iron before it dies out. The transverse size of a hadron shower is several centimeters; that of electron showers is about one centimeter in lead. In both kinds of showers, a measurement of the total ionization gives the energy of the incident particle.

Alvin Tollestrup

Electrically neutral particles don't ionize, but they can nevertheless

Dave Sanders

be detected. The most commonly encountered neutral particles are high-energy photons or gamma rays. When they enter heavy matter, they start a shower much like electrons. Therefore a signal for photons is no track in a gas-filled detector, followed by a small dense shower in a lead-filled detector (usually called a shower counter). Neutral hadrons exist and they usually produce large, spread-out showers in lead and iron, much like charged hadrons. Neutral leptons, known as neutrinos, don't ionize and interact so weakly that they penetrate any practical detector leaving no signal of their presence, except for the missing energy and momentum they carry away.

Equipped with these tools of the detector builder's trade, we can understand what goes into CDF. Let us follow a particle created in a collision at the intersection of the beams. It first travels through vacuum until it passes through the 3-inch diameter vacuum pipe that carries the beams. Next, the particle encounters gas-filled tracking chambers that measure trajectories of charged particles. There is a strong magnetic field in this region of the detector produced by a 3 meter diameter by 5 meter long superconducting solenoid coil. Charged particles bend in this field, the amount of bend is related to their momentum. By measuring trajectories in the tracking chambers, we know where charged particles are going, and we can measure their momenta.

Next, the particle encounters shower counters. Depending on the production angle, different types of shower counters are used. For angles between 2 and 10 degrees with respect to the beam line, particles exit the hole in the end of the magnet and travel to the forward or backward shower counters that are made with thin lead sheets, separated by gas-filled chambers to measure ionization in the showers. For angles between 10 and 30 degrees, particles hit shower counters

Muzafer Atac

mounted on the end caps of the magnet; these are also made from lead sheets and gas-filled chambers. At larger angles, particles must penetrate the solenoid coil before entering the central shower counters which are made from sheets of lead sandwiched with sheets of scintillating plastic.

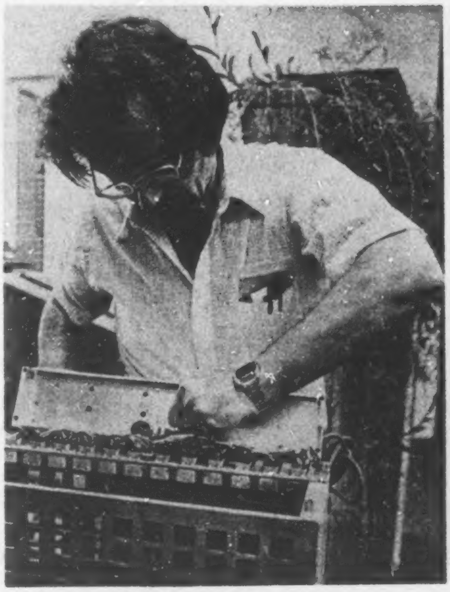
Outside all the shower counters are hadron calorimeters made of plates of steel separated by ionization detectors, either gas-filled chambers or more scintillating plastic. The plates are typically one or two inches thick depending on the region of the detector and have enough plates to give at least a meter of iron total thickness.

Ionization deposited in the various shower counters and hadron calorimeters is collected in cells called "towers" that point back to the intersection region of the beams. These towers can be thought of as forming a compound eye to look at the proton-antiproton collisions. The sizes and locations of the towers are carefully chosen to match the kinds of physics measurements we hope to make.

There are approximately 4000 towers in both the shower counters and hadron calorimeters. A single electron will usually show up in only one shower-counter cell; a typical jet of hadrons will deposit most of its ionization in 5 to 10 adjacent shower-counter and hadron-calorimeter cells. In an average event, 50 to 100 charged tracks will be seen in the gas-filled tracking chambers; many of these are uninteresting debris from the beam jets and others will be clustered in the jets of interest or will be isolated leptons.

Finally, outside all of this iron and lead we place more tracking chambers to measure the tracks of any muons that penetrate the entire detector. In the forward and backward regions, there are additional iron toroids that are magnetized to provide a measurement of

John Yoh



John Elias

the momentum of muons produced at these small angles where the solenoid measurement is less effective.

A great deal of mechanical engineering effort has gone into holding up the several thousand tons of detectors in CDF. The requirement that we minimize any dead regions, not sensitive to the particles we need to measure, makes the mechanical problems especially difficult.

One interesting solution is the use of "Roman arches" that are built out of the shower counters and hadron calorimeters that detect particles in the central region of angles. A total of four Roman arches will be built for CDF.

Other innovative designs provide for moving the entire detector in and out of the B0 collision hall rapidly when the Tevatron switches between colliding beam and fixed-target running. The main structure for moving the detector and supporting the Roman arches is the 1200-ton iron return yoke of the solenoid magnet.

The detector and mechanical components are only a part of CDF. We must also extract signals from the detectors and make sense out of them. There are more than 50,000 channels of information to be processed on any given collision event. Most of these have no signals in them, but every detector element struck by a particle provides analog or timing information that must be digitized and recorded for analysis. This is the job of the "front-end electronics" and the "data-acquisition electronics."

Front-end electronics consists of sensitive amplifiers, analog-to-digital converters, fast timing circuits, and so on, connected to the detector components. We are planning to mount much of this electronics right on the detector to minimize cable runs, thus improving signal quality. After the

Ryuji Yamada

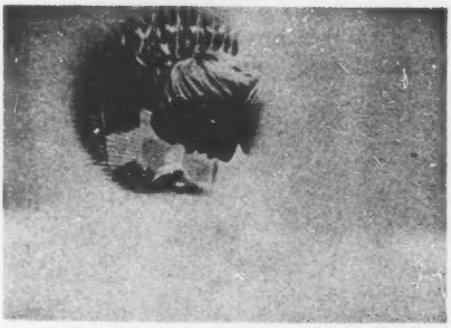
Richard Kadel

front-end electronics digitizes the signals and ignores channels that were not hit by particles, the data-acquisition electronics must bring all of the data together into computers for further analysis and storage. Because of the special demands made by a detector such as CDF, much of this electronics is state-of-the-art and must be designed specifically for CDF.

From the design intensity of the Tevatron collider and extrapolations of experience at lower energies, we estimate that the rate for producing events giving signals in CDF will be about 50,000 per second. This is much too high for our data acquisition and computer systems to handle. Most of these collisions are uninteresting from a physics standpoint because the quarks pass too far from one another to have the very hard collisions we want to study. The rate of events we want to study is probably less than one per second. Therefore, we need a trigger system that keeps the interesting events and rejects all the others. This is done in CDF by a special electronics system that interrogates signals coming out of the detector components and makes fast decisions to save or reject the event. Physicists will be able to program into the trigger system patterns of events they want to keep. For example, to select events containing jets, the trigger is programmed to respond when an energetic cluster of shower counter and hadron calorimeter towers is found.

An elaborate on-line computer system involving several VAX computers is being developed to control the apparatus, trouble shoot, and record data. This in itself is a major effort, requiring many man-years of programming effort. The on-line computers will become the community center for the CDF collaboration when we run on the Tevatron. They tell the physicists how well the apparatus is working and special displays will give us a first look at the physics coming out

Cathy Holmes



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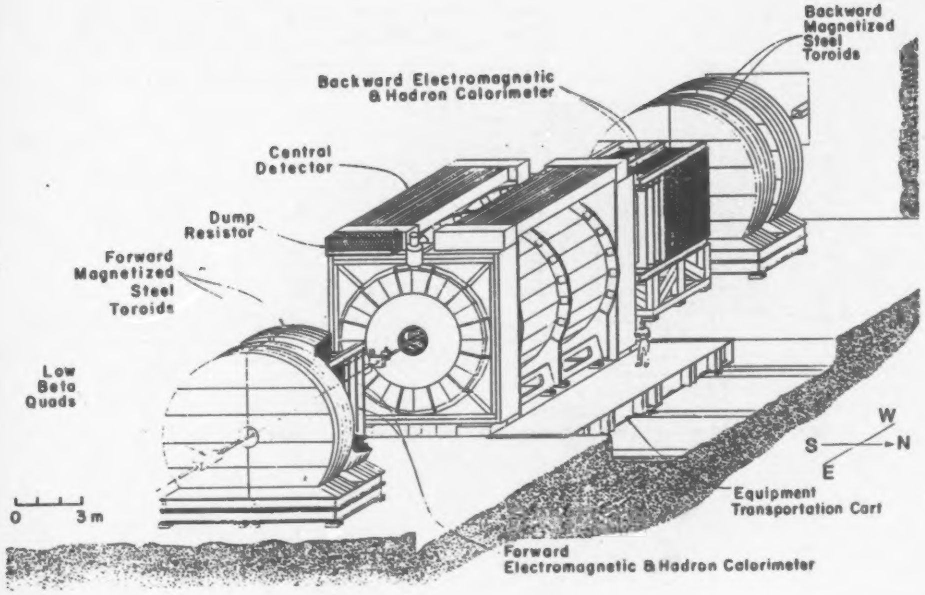
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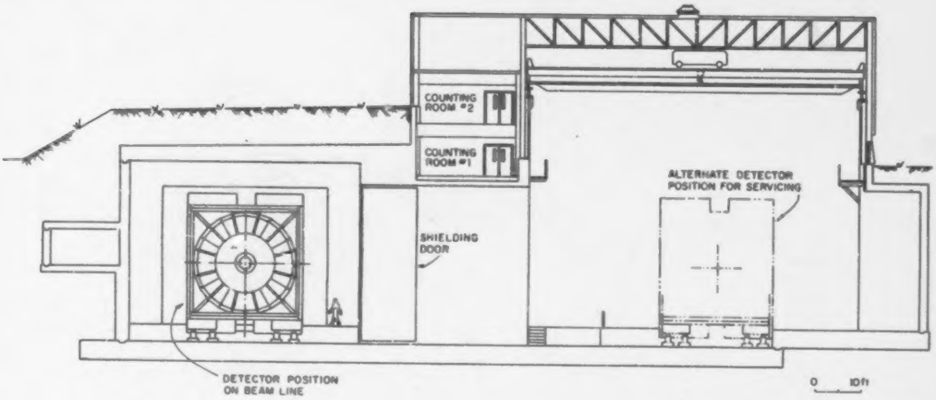
Isometric drawing of CDF.

from these experiments. The on-line computers and trigger electronics will be situated in control rooms above the B0 assembly area.

The recording of interesting events at the rate of about one a second may be the end product of the overall detector system, but it is just the beginning of the physics analysis. An off-line analysis system takes over and is programmed to reconstruct as accurately as possible the original patterns of particles in the events. Responses in the various detector elements are correlated to try to find leptons, jets, and the other particles created in these collisions. Trajectories of charged particles measured by the tracking chambers in the magnetic field will be reconstructed to determine their momenta. Physicists then will pore over these data and try to interpret them in terms of existing theories while looking for new and unexpected phenomena. While most of the data collection and analysis will be centered at Fermilab, collaborators will take summary data back to their home institutions for further analysis. Data accumulated over a few months will probably take years to digest completely.

What might we hope to see in these data? We will certainly collect events with very high energy jets. These may shed light on whether quarks have a substructure. The W and Z particles found at CERN should be produced in CDF at ten times the CERN rate. Many of their properties will be measured. A few rare events may be found where pairs of W's or Z's are produced.


COUNTING ROOM #2
COUNTING ROOM #1
ALTERNATE DETECTOR POSITION FOR SERVICING
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Cross section of CDF through B0 Collision and Assembly Hall.

These should provide sensitive tests of theories of W and Z particles. It is possible that exotic, very heavy particles will be found that decay to pairs of W's and Z's. An obscure particle, the Higgs particle, central to current theories, but as yet undetected, may be found, but its mass is not predicted. The very high energy of the Tevatron makes CDF one of the better bets for finding the Higgs. Of course, the most interesting physics to be done with CDF may not even be thought of yet.

Current Activities and Future Plans

The many pieces that go into CDF are in various stages of final design, prototyping, construction, and calibration. These activities are taking place all over the world at the institutions participating in CDF. Construction of the B0 collision hall is complete and assembly of the major detector components is beginning in the B0 assembly area. We expect to have a preliminary checkout run in May 1985. Full data-taking runs involving the entire detector will begin in early 1986.

With so many components being built at so many different places, the CDF group finds itself facing many interesting coordination problems. An example of this is the final assembly of the central shower counter-hadron calorimeter modules. These are the so-called "wedge" modules. The main steel structure is fabricated at Purdue University. The plastic scintillator material and associated light pipes are fabricated at Frascati and Pisa in Italy. Scintillator material for the shower counters is manufactured in Japan and sent to Argonne National Laboratory, where it is stacked with the lead sheets and machined to tight tolerances. Muon tracking chambers are assembled at the University of Illinois. All of these pieces show up at Industrial Building 4 at Fermilab, where they must be put together into an integrated module, outfitted with electronics, and tested. And not just one, but fifty of these modules must be completed over the next year and a half. Needless to say, it takes the hard work and a good sense of humor by many people to make this happen.

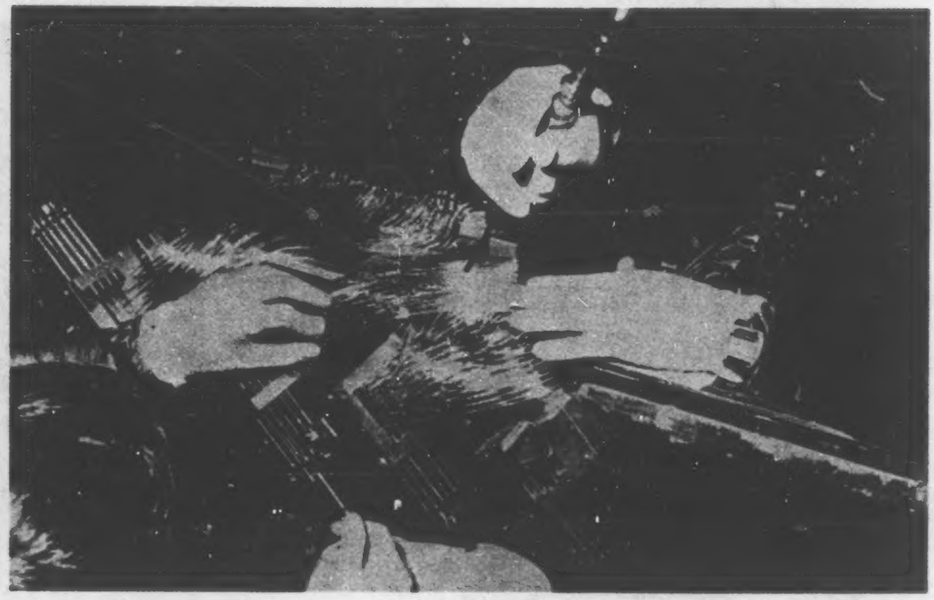
Another interesting problem in international detector-building logistics is the construction of the solenoid coil. It is being fabricated by the Hitachi Company in Japan, yet it must use standard Fermilab cryogenics equipment. Furthermore, its dimensional tolerances are absolutely crucial to the rest of the detector. Here we count on close communications between engineers and physicists at Fermilab and their colleagues at Tsukuba University and Hitachi in Japan. So far everything has progressed very well, but the moment of truth comes next spring when the coil arrives from Japan and we see whether it fits into CDF!

The wonderful success of the Doubler, progress on Tevatron I construction, and all of the detector pieces coming together make this a very exciting time for everyone working on CDF. Given a little luck, we should see the first proton-antiproton collisions within two years. Three years from now, the physicists of CDF will begin charting a new world of very high energy quark and lepton physics.

Roy F. Schwitters

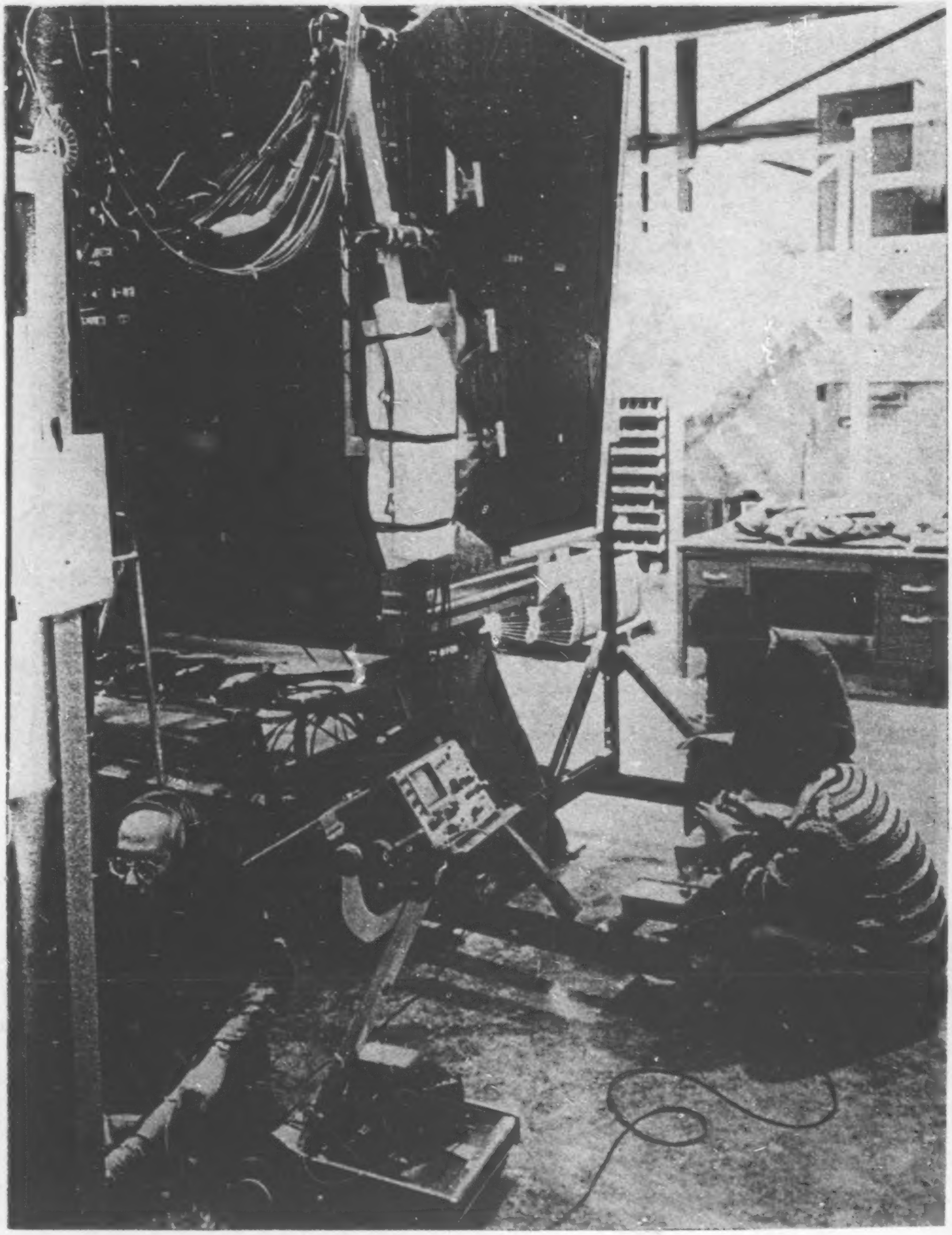
CDF wedge calorimeter assembly line in Industrial Building 4.

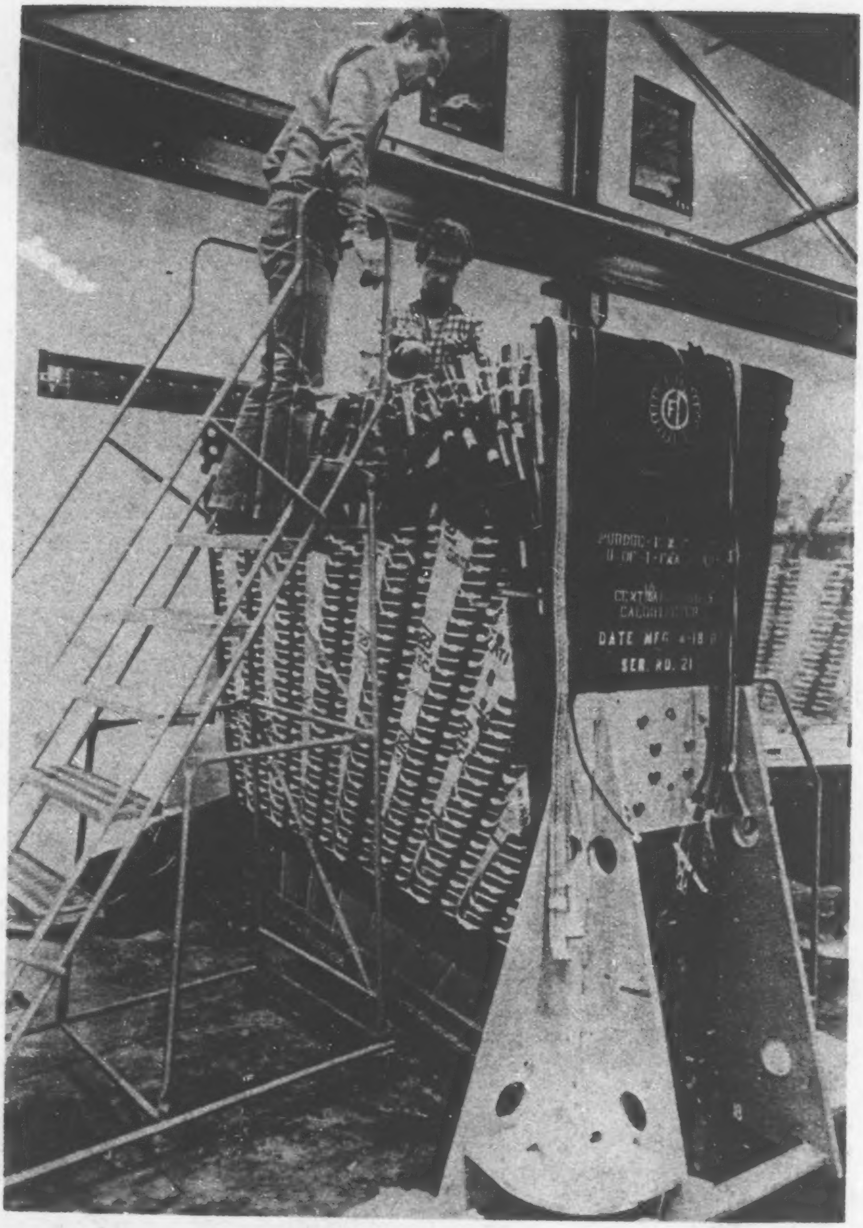
Alessandro Di Virgilio, Massimo Santoni, and Andrea Sansoni assemble light pipes in Frascati, Italy.



Closeup of light pipes in a CDF wedge calorimeter.

Japanese collaborators (left ro right Shoji Mikamo, Kiyoshi Yasuoka, and Akihiro Yamashita) set up cosmic-ray test stand for wedge calorimeter. →

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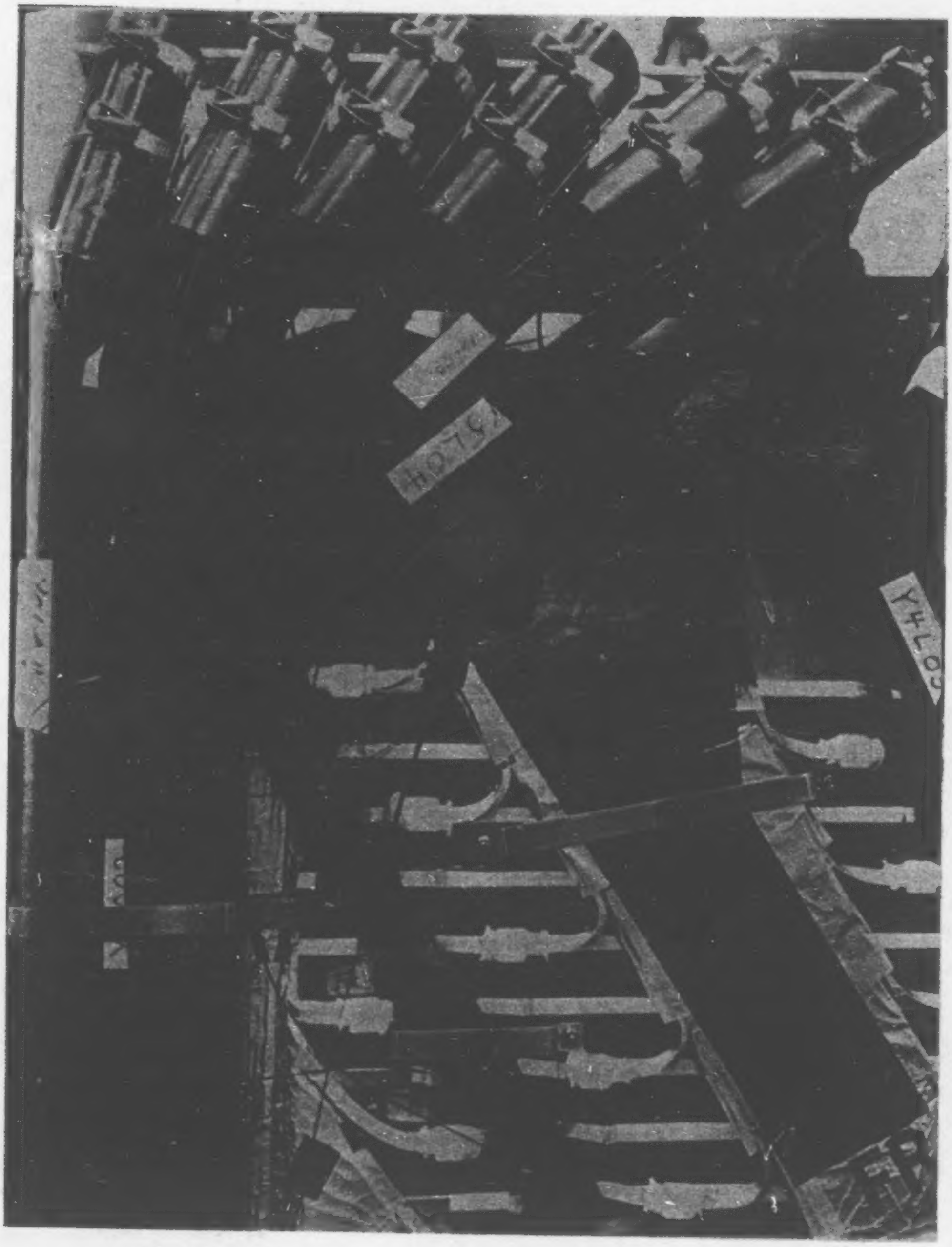
Rich Krull (left) and Don Tinsley assemble a central calorimeter wedge module.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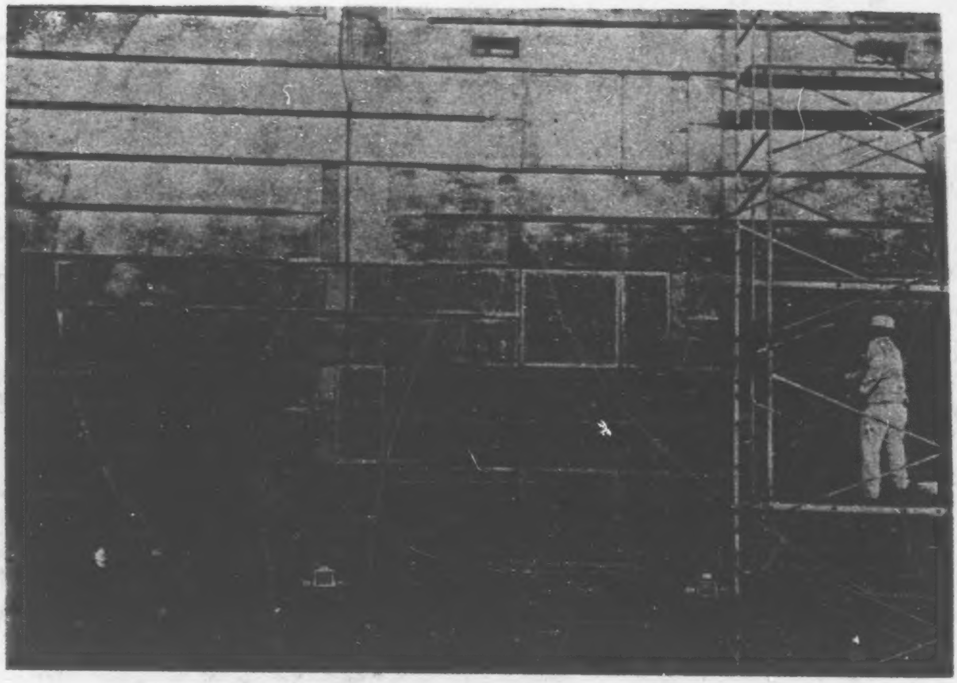
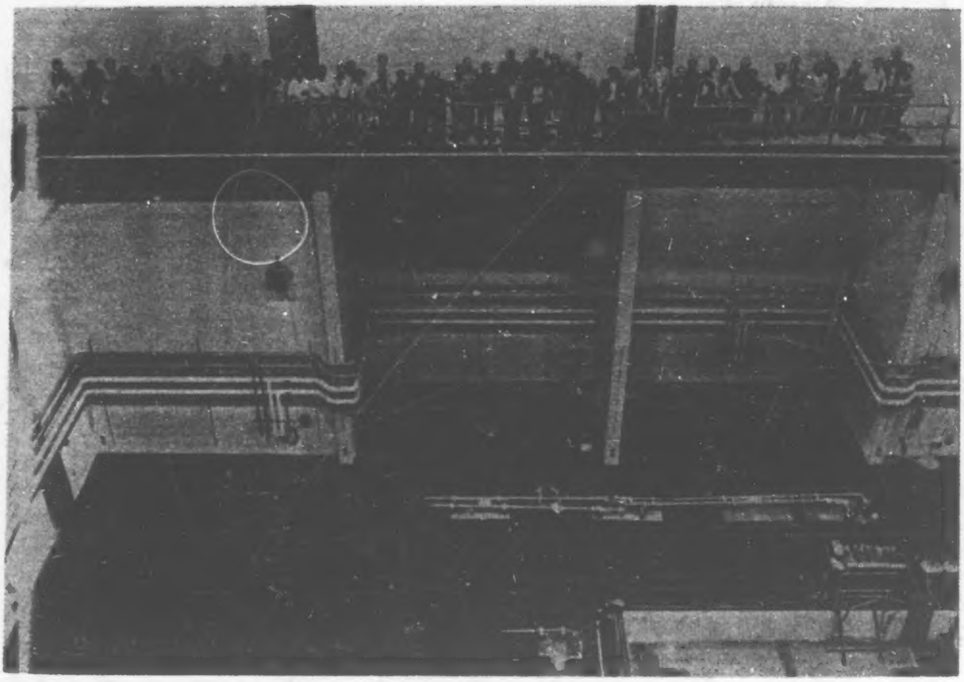
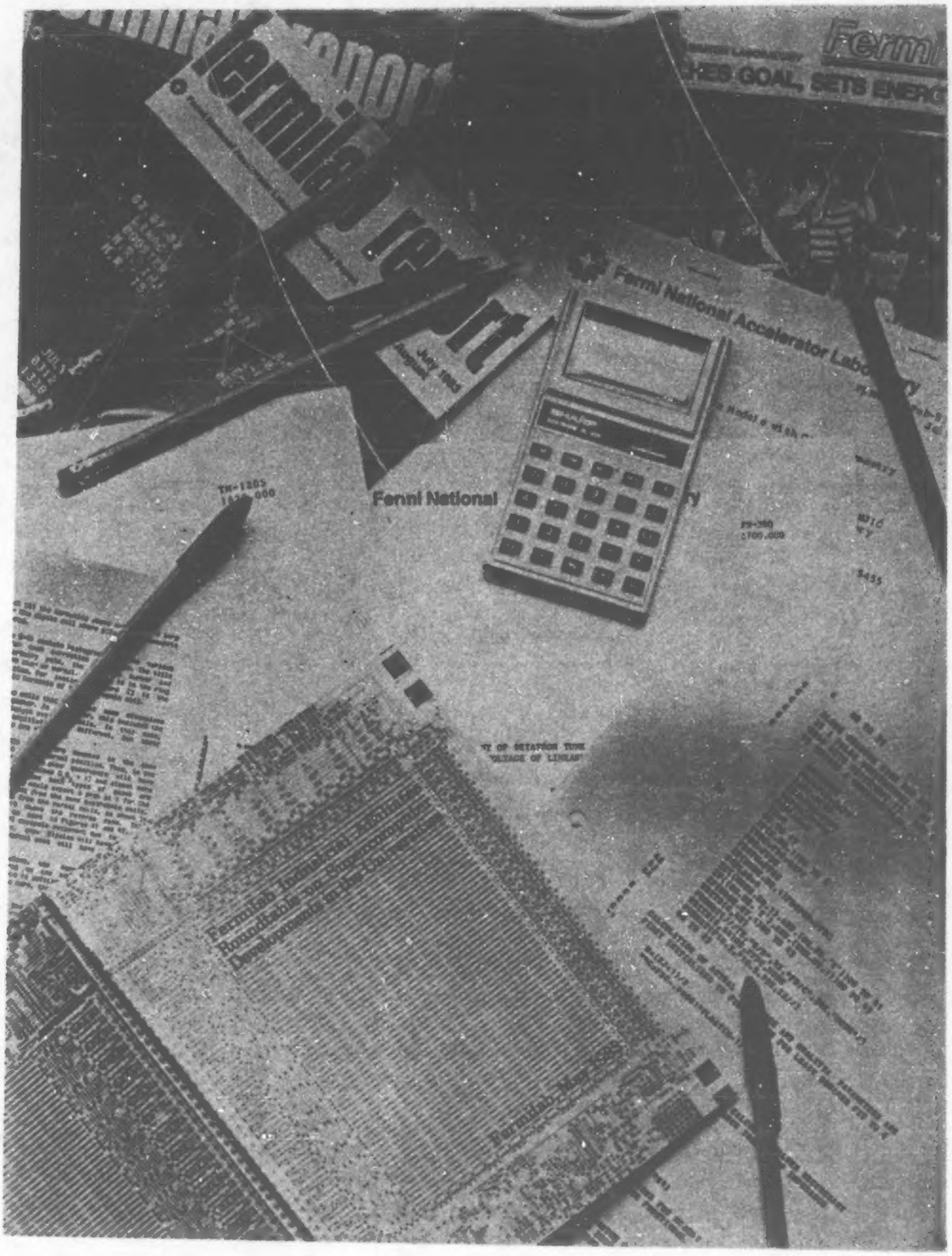


Painting the rolling door at the B0 collision hall.

← Closeup of light pipes and phototubes on a CDF wedge calorimeter.



CDF collaborators in B0 Assembly Hall during a workshop meeting on early CDF runs.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IV. Publications

HIGH ENERGY PHYSICS PROGRAM EXPERIMENTAL PUBLICATIONS*

15-Ft Neutrino/H_2& Ne #28

CHARACTERISTICS OF NEUTRAL-CURRENT INTERACTIONS INDUCED BY NEUTRINOS. J. Marriner et al., Phys. Rev. **D27**, 2569 (1983).

Multiparticle #110

STUDY OF A_2 PRODUCTION IN THE REACTION $\pi^-p \to K^0K^-p$ AT 50, 100, AND 175 GeV/c. C. Bromberg et al., Phys. Rev. **D27**, 1 (1983).

Photoproduction #152

A LARGE-SOLID-ANGLE SPECTROMETER FOR HIGH-ENERGY ELECTRONS AND PHOTONS. A. M. Breakstone et al., Nucl. Instrum. Methods **211**, 73 (1983).

Muon #203/391

MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION IN IRON USING 215- AND 93-GeV MUONS. A. R. Clark et al., Phys. Rev. Lett. **51**, 1826 (1983).

Emulsion/Protons @ 300 GeV/c #232

DELAYED CASCADES. D. T. King. Phys. Rev. **D27**, 647 (1983).

Hadron Jets #236

A MEASUREMENT OF HIGH-p_T CORRELATIONS IN 340 GeV/c pp AND 280 GeV/c π^-p REACTIONS. W. P. Oliver et al., Nucl. Phys. **B228**, 439 (1983).

Pion Inclusive #258

INCLUSIVE PRODUCTION OF HADRONS AT HIGH P_T IN 200 AND 300 GeV π^-p AND π^--NUCLEUS COLLISIONS. H. J. Frisch et al., Phys. Rev. **D27**, 1001 (1983).

Hadron Dissociation #272

MEASUREMENT OF THE RADIATIVE WIDTH OF THE K^{*+} (890). C. Chandlee et al., Phys. Rev. Lett. **51**, 168 (1983).

CALIBRATION AND PERFORMANCE OF A DRIFT CHAMBER SPECTROMETER. C. Chandlee et al., Nucl. Instrum. Methods **215**, 369 (1983).

THREE PION PRODUCTION ON NUCLEI AT 200 GeV. M. Zielinski et al., Z. Phys. **C16**, 197 (1983).

RADIATIVE DECAY WIDTH OF THE ρ^- MESON. T. Jensen et al., Phys. Rev. **D27**, 26 (1983).

Backward Scattering #290

PION-PROTON BACKWARD ELASTIC SCATTERING BETWEEN 30 AND 90 GeV/c. W. F. Baker et al., Phys. Rev. **D27**, 1999 (1983).

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*This list was compiled using 1982 (not in **Fermilab 1982**) and 1983 journal articles, theses, and conference papers. Some conference papers were submitted to a conference prior to 1983 but were not published until 1983. If there are changes, omissions, or comments, please notify the Publications Office.

30-In. Hybrid #299

THE REACTIONS $pp \to pp\pi^+\pi^-$, $K^+p \to K^+p\pi^+\pi^-$, $\pi^+p \to \pi^+p\pi^+\pi^-$ AND $\pi^-p \to \pi^-p\pi^+\pi^-$ AT 147 GeV/c. D. H. Brick et al., Z. Phys. C19, 1 (1983).

Emulsion/Protons @ 400 GeV/c #385

MULTIPLICITY DISTRIBUTIONS IN PROTON-NEUTRON INTERACTIONS AT 400 GeV/c. D. K. Bhattacharjee et al., Can. J. Phys. 61, 523 (1983).

TARGET NUCLEUS EXCITATION DEPENDENCE OF CORRELATION IN THE MULTIPLE PRODUCTION ON NUCLEI AT 400 GeV AND THE ADDITIVE QUARK MODEL. D. Ghosh et al., Can. J. Phys. 61, 1308 (1983).

15-Ft Antineutrino/H_2 & Ne #388

$\bar{\nu}_\mu$ NUCLEON CHARGED-CURRENT TOTAL CROSS SECTION FOR 5-250 GeV. G. N. Taylor et al., Phys. Rev. Lett. 51, 739 (1983).

LIMITS ON THE NEUTRINO OSCILLATIONS $\bar{\nu}_\mu \to \bar{\nu}_e$ AND $\bar{\nu}_\mu \to \bar{\nu}_\tau$ USING A NARROW-BAND BEAM. G. N. Taylor et al., Phys. Rev. D28, 2705 (1983).

Photoproduction #401

ψ' PHOTOPRODUCTION AT A MEAN ENERGY OF 150 GEV. M. Binkley et al., Phys. Rev. Lett. 50, 302 (1983).

Inclusive Scattering #451

EXPERIMENTAL STUDY OF THE A DEPENDENCE OF INCLUSIVE HADRON FRAGMENTATION. D. S. Barton et al., Phys. Rev. D27, 2580 (1983).

Charged Hyperon #497

PRECISE MEASUREMENT OF THE Σ^+ MAGNETIC MOMENT. C. Ankenbrandt et al., Phys. Rev. Letters 51, 863 (1983).

Neutrino #531

CHARMED HADRON PRODUCTION BY NEUTRINOS. N. Ushida et al., Phys. Lett. 121B, 292 (1983).

CROSS SECTIONS FOR CHARM PRODUCTION BY NEUTRINOS. N. Ushida et al., 121B, 287 (1983).

Di-Muon #537

A FAST PROCESSOR FOR DILEPTON TRIGGERS. H. Areti et al., Nucl. Instrum. Methods 212, 135 (1983).

15-Ft Neutrino/D_2 & Hiz #545

CHARGED-PARTICLE MULTIPLICITY DISTRIBUTIONS IN νn AND νp CHARGED-CURRENT INTERACTIONS. D. Zieminska et al., Phys. Rev. D27, 47 (1983).

QUASIELASTIC CHARMED-BARYON PRODUCTION AND EXCLUSIVE STRANGE-PARTICLE PRODUCTION BY HIGH-ENERGY NEUTRINOS. D. Son et al., Phys. Rev. D28, 2129 (1983).

STUDY OF DIQUARK FRAGMENTATION INTO Λ AND Y^{*+} IN νn AND νp INTERACTIONS. C. C. Chang et al., Phys. Rev. D27, 2776 (1983).

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15-Ft Neutrino/H_2 & Ne #546

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EVIDENCE FOR HARD GLUON BREMSSTRAHLUNG IN A NEUTRINO EXPERIMENT. M. D. Sokoloff, Ph.D. Thesis, University of California, Berkeley, May 1983.

Hadron Jets #557

PRODUCTION OF HIGH-TRANSVERSE-ENERGY EVENTS IN p-NUCLEUS COLLISIONS AT 400 GeV/c. B. Brown et al., Phys. Rev. Lett. 50, 11 (1983).

Elastic Scattering #577

ELASTIC SCATTERING OF $\pi^\pm$ AND $K^\pm$ ON PROTONS AT 100 AND 200 GeV/c. R. M. Kalbach et al., Phys. Rev. D27, 2752 (1983).

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High Mass Pairs #605

PROGRESS IN CHERENKOV RING IMAGING. PART 2: IDENTIFICATION OF CHARGED HADRONS AT 200 GeV/c. Ph. Mangeot et al., Nucl. Instrum. Methods 216, 79 (1983).

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STRANGE-QUARK SUPPRESSION IN 225-GeV/c π^- Be INTERACTIONS. P. Schoessow et al., Phys. Rev. D28, 1773 (1983).

Neutrino #616

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Collider Detector at D0 Area #740

RESPONSE OF A HIGHLY SEGMENTED EXTRUDED LEAD GLASS CALORIMETER TO ELECTRONS AND PIONS BETWEEN 15 AND 45 GeV/c. R. Engelmann et al., Nucl. Instrum. Methods 216, 45 (1983).

Collider Detector Facility P741

SATURATED AVALANCHE CALORIMETER. M. Atac et al., Nucl. Instrum. Methods 205, 113 (1983).

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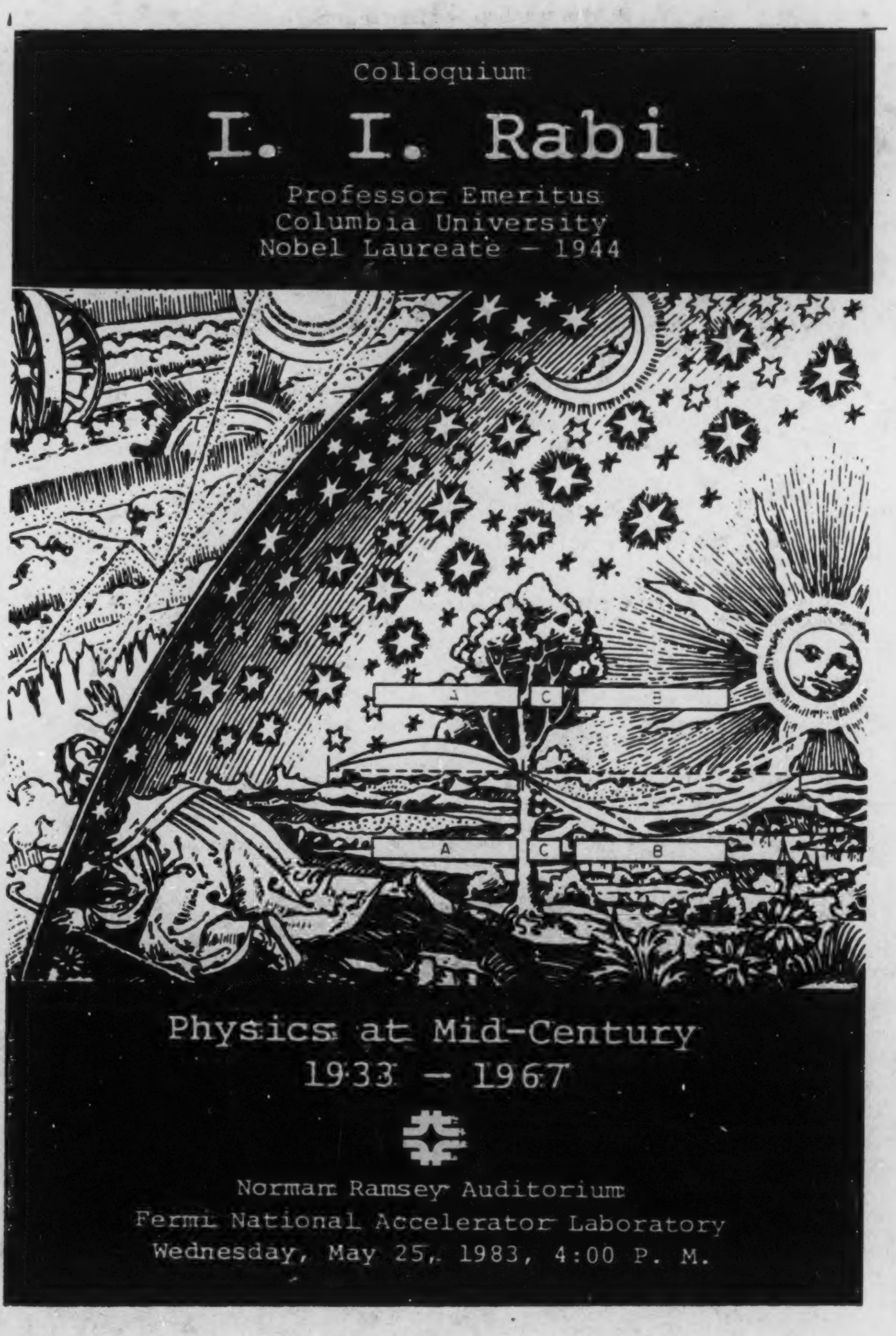

Colloquium

I. I. Rabi

Professor Emeritus
Columbia University
Nobel Laureate – 1944

Physics at Mid-Century
1933 – 1967

Norman Ramsey Auditorium
Fermi National Accelerator Laboratory
Wednesday, May 25, 1983, 4:00 P. M.

V. 1983 Workshop and Seminar Series

Joint Experimental—Theoretical Physics Seminars

Reiner Wilcke, Cornell University, "Decays the b-Quark"(CLEO Collaboration), January 28, 1983

Peter Igo-Kemenes, Columbia University, "Measurements of Hyperon β-Decays at CERN," February 11, 1983

Milind Purohit, CALTECH, "Structure Functions, R, and QCD Results from the CCFR Experiment," February 18, 1983

Marvin Marshak, University of Minnesota, "Multiple Muon Events at Soudan Mine," February 18, 1983

George Sterman, SUNY-Stony Brook, "The Shape of the KNO Scaling Function in QCD," February 25, 1983

Cathy Newman, Princeton University, "Recent Results on J/ψ Radiative Decays," February 21, 1983

Harry Weerts, Fermilab, "Limits on Neutrino Oscillations from E594," March 4, 1983

Jim Linneman, CERN, "High p_T Trigger EM Calorimeter at ISR," March 10, 1983

K. B. Luk, Rugters University, "Almost Everything You Ever Wanted to Know About the Ω^-," (E620), March 11, 1983

Milind Purohit, Caltech, "Stucture Functions, R and QCD Results from the CCFR Experiment," March 18, 1983

Michael Crisler, Ohio State University, "Resent Results from E613," April 1, 1983

Peter Weilhammer, CERN, "Measurement of Charged Particle Production Hadron Interactions at the CERN SPS," April 22 1983

Scott Whitker, MIT, "Latest Results from a Flash Chamber Proportional Tube ν Detector at Fermilab," April 15, 1983

Art Rich, University of Michigan, "New Tests of the Weak Interactions and QED Using Positrons and Positronium," May 6, 1983

Fred Lopez, University of Illinois (Chicago), "Can a Fixed Target Calorimeter Experiment Observe Hard Scattering Effects?" (E-537), May 13, 1983

John Hagelin, SLAC, "Discovering Supersymmetry with Today's Accelerators," May 13, 1983

Peter McIntyre, Texas A&M University, "A 10 TeV × 10 TeV to 50 Tev × 50 TeV Collider for $200 to $500 Million Now!" May 17, 1983

Gikas Mageras, Max Planck Institute, "Transitions of the T Systems," May 20, 1983

M. Shaevitz, Columbia University, "Results from the E701 Neutrino Oscillation Experiment," May 27, 1983

Kristos Sliwa, Fermilab, "First Results from the Tagged γ Spectrometer," June 10, 1983

Byron Lundberg, University of Wisconsin, "Inclusive Λ Polarization at Large P_T," June 17, 1983

Mike Arenton, Argonne National Laboratory, "Hadron Jets at Fermilab; Results from E609," June 24, 1983

Norman McCubbin, CERN, "Jet Physics From R807 at the ISR," June 30, 1983

Andre Rousserie, Saclay, "New Results of the UA2 Experiment," June 30, 1983

Helfried Burckhardt, Heidelberg University/CERN, "Observation of a Narrow Resonance at 2.46 GeV - A Candidate for the Charmed-Strange Baryon A^+," June 30, 1983

R. Castaldi, CERN, "The UA4 Collider Experiment on $\bar{p}p$ Elastric and Total Cross Section," July 8, 1983

Walter Wagner, University of Aachen, Germany, "Structure Functions Measurements in Two Photon Physics," July 15, 1983

S. Lokanathan, Jaipur University, India, "The Experimental Status of Anomalons," July 29, 1983

Jean-Paul Repellin, CERN, "Observation of W and Z^0 Decays into Electrons and Neutrinos in the UA2 Experiment," August 1, 1983

G. Preparata, Universita di Bari, "Partons vs. Hadrons: A Physical Theory of Fragmentation," August 10, 1983

T. Curtright, University of Florida, "Weak-Coupling Limit of Liouville Field Theories," August 12, 1983

C. Quiqq, Fermilab, "Auguries and Portents," October 14, 1983

M. Nelson, Lawrence Berkeley Laboratory, "Lifetimes of Heavy Quarks and Leptons--Mark II," October 28, 1983

S. Errede, University of Michigan, "IMB Update," October 28, 1983

W. Smith, Nevis Labs, "Neutrino Production of Dimuons," November 4, 1983

D. Hitlin, CALTECH, "Mark III Results on ψ Radiative Decays and Review of Glueball Candidates," November 11, 1983

F. Pauss, CERN, "Recent Results from UA-1 On $W^\pm$ and Z^0," November 9, 1983

D. Noop, CALTECH, "Prompt Electrons from Delco," December 2, 1983

M. Kuchnir, Fermilab, "Chicago-Fermilab Monopole Search," December 9, 1983

L. McLerran, University of Washington, "The Quark-Gluon Plasma," December 16, 1983

R. Zhu, Massachusetts Institute of Technology, "Latest Results of the Mark-J Experiment," December 16, 1983

Theoretical—Astrophysics Seminars

James Hartle, University of Chicago, "Quantum Dynamic of the Early Universe," January 7, 1983

George Fuller, University of Chicago, "Evolution of Supermassive Stars," January 14, 1983

Richard Kron, University of Chicago, "Evolution of Distant Galaxies and Quasars," January 21, 1983

Don York, University of Chicago, "Measuring Big Bang Artifacts: D, ^{3}He, ^{4}He," Janurary 28, 1983

Katherine Freese, University of Chicago, Cosmological Constraints on Neutrino Masses," February 11, 1983

Joan Centrella, University of Illinois, "The Large-Scale Structure of the Universe," February 14, 1983

Robert Kirshner, University of Michigan, "The Texture of the Universe," February 18, 1983

Marc Davis, University of California, Berkeley, "The Structure of the Universe," February 25, 1983

Peter Meyer, Enrico Fermi Institute, "A Space Experiment: Cosmic Ray Composition at Very High Energies," March 4, 1983

Joe Taylor, Princeton University, "Pulsars," April 1, 1983

John Ellis, SLAC/CERN, "Supersymmetry, Cosmology and Inflation," April 8, 1983

David T. Wilkinson, Princeton University, "Anisotropies in the Background Radiation," April 15, 1983

Jon Arons, University of California - Berkeley, "The Fast Pulsar," April 29, 1983

Pat Palmer, University of Chicago, "Interstellar Molecule," May 6, 1983

Eugene Loh, University of Utah, "The Fly's Eye," May 13, 1983

David S. P. Dearborn, University of Arizona, "Astronomy of the Incas," May 20, 1983

G. Steigman, Bartol Res. Found./University of Chicago, "Messengers from the Big Bang," May 17, 1983

Myron L. Good, Stonybrook, "Self-Consistent Solution for a Pulsar Magnetosphere," September 15, 1983

J. Hawley, University of Illinois/Champaign-Urbana, "2-D Black Hole Accretion and Thick Disks—A Numerical Approach," September 29, 1983

Piero Galeotti, University of Torino, "Report on the Mont Blanc Proton-Decay and Neutrino-Astronomy Detector," October 10, 1983

A. Melott, University of Chicago, "The Connection between Elementary Particles and the Formation of Superclusters of Galaxies," October 13, 1983

L. Krauss, Harvard University, "Neutrinos from Heaven to Earth," October 20, 1983

Willy Fischler, University of Texas, "The Entropy Crisis of Supersymmetric Theories," October 27, 1983

Piet Hut, Princeton, "3-Body Scattering Experiments: Binaries as an Energy Source in Stellar Dynamics," November 3, 1983

Demosthenes Kazanas, NASA, "A Model for Active Galactic Nuclei," November 10, 1983

Dennis Hegyi, Michigan, "Problems with Baryonic Galactic Halos," November 17, 1983

Stirling Colgate, Los Alamos National Laboratory, "Gamma Ray Bursts," November 30, 1983

R. Epstein, Los Alamos National Laboratory, "An Extremely Simple Model of Galaxy Formation," December 1, 1983

Robert Brandenberger, ITP-U, University of California, Santa Barbara, "Density Fluctuations in Inflationary Universe Models," December 8, 1983

Joe Silk, University of California, Berkeley, "From Particles to Pancakes: The Large Scale Structure of the Universe," December 15, 1983

Theoretical Physics Seminars

Nina Byers, University of California, Los Angeles, "T Spectroscopy," February 8, 1983

Daniel Caldi, Lawrence Berkeley Laboratory, "Can a Gambler Tell the Difference Between 1 and 2?--A Monte Carlo Analysis of U (1) Gauge Theory," February 15, 1983

L. Hall, Lawrence Berkeley Laboratory, "Two-Sector Models in N=1 Supergravity," February 17, 1983

E. Tomboulis, Princeton University, "Permanent Confinement in Four Dimensions," February 22, 1983

W. van Neerven, NIKHEF, Amsterdam, "How Reliable is the Drell-Yan Mechanism for W Production?" March 1, 1983

R. Gupta, Northeastern University, "Calculation of Hadron Spectrum in Lattice QCD," March 8, 1983

Sinan Kaptanoglu, SUNY - Stony Brook, "A Class of Gauge Theories which Remain Renormalizable in the Infinite Coupling Constant Limit," March 10, 1983

Carl Albright, Northern Illinois University/Fermilab, "Preon models of Composite Quarks and Leptons," March 15, 1983

John Ralston, Argonne National Laboratory, "High Energy Phase Evolution and Interference In Perturbative QCD," March 22, 1983

Y. Zazama, Kyoto Univeristy, Japan, "More About Monopole-Fermion Dynamic: Subtleties of the Boundary Conditions," March 17, 1983

M. Bander, University of California - Irvine, "Quark-Antiquark Bound States," March 24, 2983

J. Polchinski, Harvard University, "Low Energy Supergravity," March 29, 1983

P. Goddard, University of Cambridge, "Monopole Solutions to Gauge Theories," April 5, 1983

K. Sibold, CERN, "On the Off-Shell Infrared Problem of Supersymmetric Gauge Theories," April 12, 1983

J. Kim, Caltech, "General Method for Minimizing Group Invariant Scalar Potentials," April 18, 1983

G. Farrar, Rutgers University, "Exclusive Hadron Scattering," April 19, 1983

W. Celmaster, Northeastern University, "Gauge Theories on a Body Centered Tesseract," April 26, 1983

A. Duncan, University of Pittsburgh, "Stieltjes Spectral Analysis of Hamiltonian Lattice Field Theories," May 3, 1983

J. Schwarz, CALTECH, "Supergravity and Superstrings," May 10, 1983

G. Martinelli, INFN Frascati, "Monte Carlo Simulation of QCD on a $10^3 \times 20$ Lattice: Results for Hadron Spectroscopy," May 16, 1983

J. Rabin, Yale University, "Supersymmetry on a Super-Lattice," May 17, 1983

D. Wallace, Edinburgh University, "Numerical Simulation on the LCL Distributed Array Processor," May 20, 1983

P. Orland, Imperial College, "Actions for Chromoelectric Superconductors," May 24, 1983

K. Ellis, INFN-Rome, "Unravelling Higher Twists," May 31, 1983

D. Wilkinson, Schlumberger-Doll Research, "Percolation Theory and Two-Phase Flow in Porous Media," June 7, 1983

B. Zumino, University of California, Berkeley, "Supersymmetry and Topology," June 14, 1983

N. Seiberg, Institute for Advanced Study, "The Massless Limit of Supersymmetric QCD," June 21, 1983

M. K. Gaillard, University of California, Berkeley, "Scalar Masses in Locally Supersymmetric Theories," June 23, 1983

H. M. Nussenzveig, University of Sao Paulo, "Rainbow and Glory Scattering," June 27, 1983

M. Moshe, FERMILAB/Technion, "Ground State Stability in Large N Field Theory," June 28, 1983

J. Rosner, Enrico Fermi Institute, "Heavy Neutral Leptons," July 5, 1983

T. Barnes, Rutherford Laboratory, "Hermaphrodites—Mixed States of Quarks and Gluons," July 12, 1983

D. Horn, Tel Aviv University, "Variational Calculation of the Vacuum Mean Field and Beyond," July 18, 1983

P. Mackenzie, Fermilab, "Rho Goes to Pi-Pi on the Lattice," July 19, 1983

R. Barbieri, University of Pisa, "Composite Quarks and Leptons," July 21, 1983

R. Barbieri, University of Pisa, "Supersymmetry, Supergravity and Their Phenomenological Implications," July 25, 1983

P. Landshofff, Cambridge University, "P-P and $\bar{P}$-P Elastic Scattering," July 26, 1983

B. Ovrut, Rockefeller University, "The Locally Supersymmetric Geometrical Hierarchy Model," July 28, 1983

Y. Hosotani, University of Pennsylvania, "Dynamical Gauge Symmetry Breaking and Left-Right Assymmetry in Higher Dimensional Theories," August 2, 1983

E. Rabinovici, Hebrew University, "Monte Carlo Studies of the Liouville Model," August 23, 1983

T. Muta, Hiroshima University, "Higher-Order Effects in Electroweak Theory," August 30, 1983

A. Zepeda, CINVESTAV, Mexico, "Flavor Diagonal Neutral Currents From Extended Hypercolor," September 6, 1983

J. H. Kuhn, ITP-Aachen, "Radiative Quarkonium Decays," September 13, 1983

C. Bender, Washington University, "New Quantum Theory on a Lattice," September 20, 1983

A. Khare, Bhubaneswar, "Dynamical Breaking of Supersymmetry in Quantum Mechanics," September 22, 1983

D. Friedan, University of Chicago, "Applications of the Virasoro Algebra in Two-Dimensional Physics (String Theory and Statistical Mechanics)," September 27, 1983

H. Lipkin, Fermilab/Weizmann, "Is the Iota a Giant Quarkonium Resonance?" September 29, 1983

B. Grossman, Rockefeller University, "Magnetic Monopole Regarded as an Impurity in the Dirac Sea," October 4, 1983

I. Bigi, Aachen/Fermilab, "On CP Violation and KM Angles," October 6, 1983

C. Nappi, Princeton University, "Soliton Model of Baryons," October 11, 1983

S. Raby, Los Alamos National Laboratory, "Neutrinos Around Us," October 18, 1983

M. Dine, IAS - Princeton, "Supersymmetry Breaking by Instantons," October 25, 1983

J. Polonyi, University of Illinois, "Microcanonical Simulation of Fermions," November 1, 1983

Marc Sher, University of California, Irvine, "Effective Potentials and the Renormalization Group: From the Standard Model to Inflation," November 15, 1983

Michael Peskin, SLAC, "Ineffective Lagrangians?" November 17, 1983

A. Sen, Fermilab, "Supersymmetric SU(6) as a Solution to the Fine Tuning and the Strong CP Problems," November 22, 1983

H. Haber, University of California, Santa Cruz, "Unusual Gluino Signatures," November 29, 1983

R. Sugar, University of California, Santa Barbara, "Numerical Simulation of Fermion Systems," December 6, 1983

H. Lipkin, Weizmann/Fermilab, "Iota-Glueball or Quarkonium Resonance," December 13, 1983

Advanced Computer Seminar Series

B. Smith, Denelcor, Inc., "Design of the HEP," January 27, 1983

H. Walsh & F. Ris, IBM, "Scientific Computers," February 3, 1983

J. Abraham, University of Illinois, "VSLI Design," March 3, 1983

G. Fox, CALTECH, "Microprocessor Arrays for Physics," February 11, 1983

S. Fernbach, Control Data Corporation, "Supercomputers, Past, Present, and Future," May 12, 1983

D. Lowendorf, Duke University, "Development and Use of an Asynchronous MIMD Computer for Finite Element Analysis," April 21, 1983

P. Cannon, Star Technology, "The Origins of a 100 Megaflop Array Processor--The Star Technology ST-100," April 28, 1983

T. Agerwalla, IBM, "How Fast Can a Single Instruction Counter Machine Execute?" July 6, 1983

S. Boutin, National Semiconductor, Chicago, "NS 16032 and Related Products," October 12, 1983

D. Gajski, University of Illinois, "CEDAR Supercomputer," October 26, 1983

Fermilab Colloquia

Dr. J. Willemsen, Schlumberger-Doll Research, "Geometric Criticality and Paths of Least Resistance," January 5, 1983

Dr. L. Eisenstein, University of Illinois, "Photon-Induced Reactions in Biomolecules: Bacteriorhodopson and Visual Pigments," January 12, 1983

Dr. M. Furth, Memorial Sloan-Kettering Institute, "Oncogenes in Viruses and in Tumors," January 19, 1983

Dr. S. Rice, University of Chicago, "The Structure of the Metal Liquid-Vapor Interface," January 26, 1983

Dr. R. Haselkorn, University of Chicago, "Genetic Engineering for Fun and Profit," February 2, 1983

Dr. A. Mueller, Columbia University, "Perturbative QCD," February 9, 1983

Dr. P. Galison, Harvard University, "How the First Neutral Current Experiments Ended," February 16, 1983

Dr. J. Vick, Exxon, "Development of the Exxon Donor Solvent (EDS) Coal Liquefaction Process," February 23, 1983

Dr. C. Will, Washington University, "General Relativity Confronts Experiment," March 9, 1983

Dr. S. Kirkpatrick, IBM, New York, "Statistical Mechanics and the Travelling Salesman," March 16, 1983

Dr. Yosef Sheffi, MIT, "Modelling Transportation Network Evacuation," March 23, 1983

Dr. P. Steinhardt, Pennsylvania University, "The New Cosmology," March 30, 1983

Dr. M. Lampton, University of California, Berkeley, "The Space Lab One Mission," April 6, 1983

Dr. S. Wolfram, The Institute for Advanced Study, "Cellular Automata and Universality in Self-Organizing Systems," April 13, 1983

Dr. J. D. Cowan, University of Chicago, "Spontaneous Symmetry Breaking in Large Scale Brain Activity—With Applications to Epilepsy and Drug Induced Visual Hallucination Patterns," April 20, 1983

Dr. L. Kirkegaard, Kirkegaard Assoc., "Architectural Acoustics," April 27, 1983

Dr. T. Oka, University of Chicago, "$H3^+$ Ion in Astrophysics," May 4, 1983

Dr. L. Frank, University of Iowa, "Imaging the Faint Lights of Earth," May 11, 1983

Dr. B. Mandelbrot, IBM Thomas J. Watson Research Center, "Now That It Is Agreed That Many Shapes of Physics are Fractal; The Question is Why?" May 18, 1983

Dr. I. I. Rabi, Columbia University, "Physics at Mid-Century 1933-67," May 25, 1983

Dr. M. Dresden, SUNY, Stony Brook, "The Lingering Effects of an Incorrect Theory: The Bohr-Kramers-Slater Considerations," June 1, 1983

Dr. B. McKee, "Nonstandard Automobiles," June 8, 1983

Dr. S. Buchsbaum, Bell Labs, "TBA," June 15, 1983

Dr. D. Held, JPL, "Synthetic Aperture Imaging Radar," June 22, 1983

Dr. M. L. Good, SUNY, Stony Brook, "Why Do Pulsars Pulse?" September 14, 1983

Dr. C. Smorynski, San Jose State University, "New Practical Applications of Godel's Incompleteness Theorems," September 21, 1983

Dr. R. York, University of Virginia, "Status Report on the National Electron Accelerator Laboratory (NEAL)," September 28, 1983

Mr. G. Ruffa, Westar Glenwood Earth Station, "A Tower Thrice as Tall as the World," October 5, 1983

Dr. C. Bennett, IBM, "Thermodynamics of Computation," October 12, 1983

Mr. J. Randi, "Science and the Chimera," October 17, 1983

Drs. J. Bartholdi & L. Platzman, Georgia Institute of Technology, "A Minimal Technology Routing System," October 26, 1983

Dr. D. Langenberg, University of Illinois, Chicago Circle, "Science and Government: The Ambivalent Relationship," November 2, 1983

Dr. G. Chanan, Columbia University, "X-Ray Quasars," November 9, 1983

Dr. M. Lacker, Courant Institute Mathematics, "Mathematics of the Menstrual Cycle," November 16, 1983

Dr. S. A. Colgate, Los Alamos National Laboratory, "Gamma Ray Bursts and Nonequilibrium Phenomena," November 30, 1983

Dr. S. Bloch, University of Chicago, "Great Moments in Mathematics: The Proof of the Mordell Conjecture," December 7, 1983

Dr. H. Stormer, Bell Laboratories, "Fractional Quantization of the Hall Effect," December 14, 1983

Research Technique Seminars

P. Olivier, Yale University/CERN; J. Sandweiss, Yale University, "Parked Electrons, Non-Ionizing Track Storage, and Other Aspects of the SSC (Super Streamer Chamber) Development Program," March 10, 1983

H. J. Seebrunner, Max-Planck Institute, "Silicon Strip Detector with High Spatial Resolution," April 12, 1983

S. Majewski, CERN, "The Ring Cherenkov Technique," September 22, 1983

D. Anderson, CERN, "BaF_2 Coupled to a Low Pressure Wire Chamber: More Than a Calorimeter," September 22, 1983

J. Crittenden, Nevis Laboratory, "Data Acquisition System for Experiment 605," October 27, 1983

S. Dhawan, Yale University, "New Developments on Flash ADC's," November 3, 1983

A. Kusumegi, KEK, "Present Status of Heavy Liquid Counter (HELICON)," November 8, 1983

A. Kreymer, Fermilab, "High Speed, High Resolution Particle Imaging Using Scintillating-Glass Fiber-Optic Plates," November 17, 1983

Arms Control and International Security Seminar Series

Ruth Adams, Bulletin of the Atomic Scientists, "The Political Realities of Arms Control," November 10, 1983

Congressman P. Simon, Candidate for U. S. Senate in Illinois, "Arms Control Issues in 1984," December 15, 1983

Workshops

Calorimeter Calibration Workshop
April 29-30, 1983

Other

Fermilab Annual Users Organization Meeting
April 22-23, 1983

Fermilab Industrial Affiliates Annual Meeting
May 19-20, 1983

12th International Conference on High-Energy Accelerators
August 11-16, 1983

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Photographs facing page 1, 35, and vignettes: Olivia Gonzales

Photographs pages 24 and 32: Anthony R. Donaldson

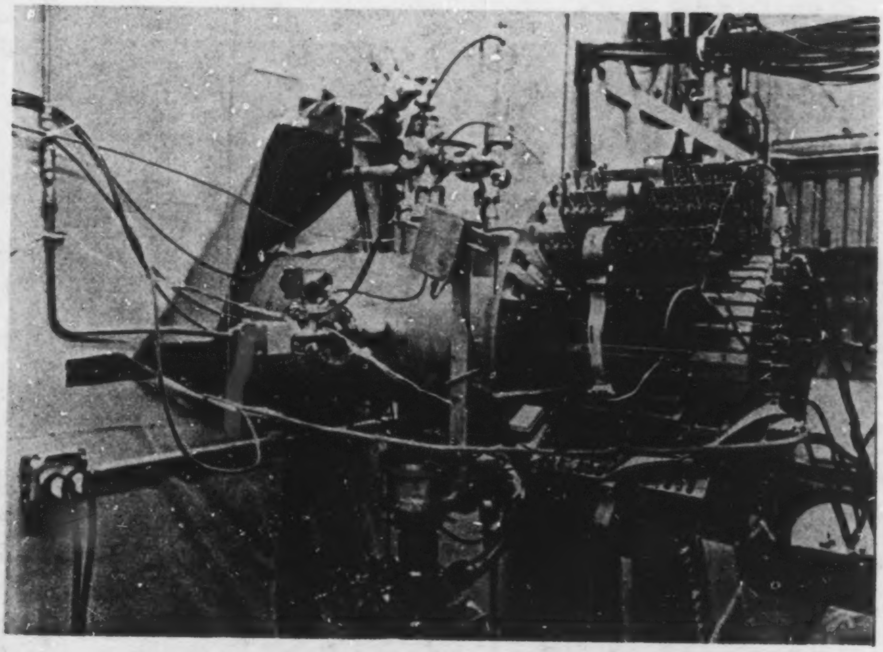
Page 33: Bruegel, "Tower of Babylon"

Page 58: Instructions for glueing the CDF end plug shower counter together.

Photography in this report was done by the Fermilab Photo Unit.

fermilab report

Fermi National Accelerator Laboratory Monthly Report
February 1984



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F. T. Cole, R. Donaldson, and L. Voyvodic, Editors

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THE COVER: A prototype detector for ring-imaging the Cherenkov light from very high energy charged particles. The 2,500 needle points in the Saclay-designed single photoelectron detector plane enable the radius of the ring image to be determined with an uncertainty of 1.6 mm. The detector is one of several detectors being studied for an eventual large-solid-angle ring-imaging system in Tevatron experiment E-665.

(Photograph by Fermilab Photo Unit)

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EARLY BIRD REPORT #871
Feburary 16, 1984

- 800 GeV BEAM HAS BEEN EXTRACTED FROM THE TEVATRON TO THE SWITCHYARD DUMP.

For the past 24 hours, the accelerator has been engaged in high energy studies. The objectives of the studies included; establishment of 800 GeV beam to switchyard and ultimately to transport the beam to the meson area. Though beam was extracted to the dump, attempts at transporting beam to the meson area were thwarted due to an inability to power up the left bend magnets.

The push for an 800 Gev ramp began early during the day shift. Recovery from two mid-afternoon quenches (770 and 700 Gev) attributed to a delay in the efforts. Improper helium flow for the magnet leads at E3 necessitated a Tevatron access at the start of the evening shift. By 1830 hrs, an 800 Gev Tevatron ramp had been established. By 2044 hrs, beam had been accelerated to flattop, and was extracted to the switchyard dump 10 minutes later.

During the owl shift, attempts were made at establishing beam to the meson experimental area. Due to a noisy transducer on the left bend power supplies, at 0400 hrs the efforts to establish beam to that area were abandoned. Tuning to increase the extracted beam intensity continued throughout the owl shift. Intensities of $>7 \times 10^{12}$ ppp were achieved.

High energy studies are scheduled to continue throughout the week.

T. Louis Williams

STATUS OF THE TEVATRON II PROJECT

Tom Kirk

The first phase of the Tevatron II project has now been operational for approximately three months. During this period, the slow-extracted beam from the Tevatron and the completely reworked beam switchyard, plus many of the Tevatron primary-target systems, have been brought into operation. Most important, the Tevatron high-energy physics program has started.

The second phase of Tevatron II will involve construction and commissioning of the new secondary beam lines. These consist of the Wide Band Photon Beam in the Proton Area, the Muon and Prompt Neutrino Beams in the Neutrino Area, and the Meson Area MW Pion and MP Polarized Proton Beams. Many of the components that will be needed for construction of these beams have already been started and plans for the associated civil-construction projects are far advanced. In some cases, the work is already underway. Next spring and summer will be a period of intense activity for the Tevatron II Project; a great deal of civil construction will take place that will ultimately house the new beam facilities. Large experimental halls needed for the experiments to be done in these beams will also be constructed in this period.

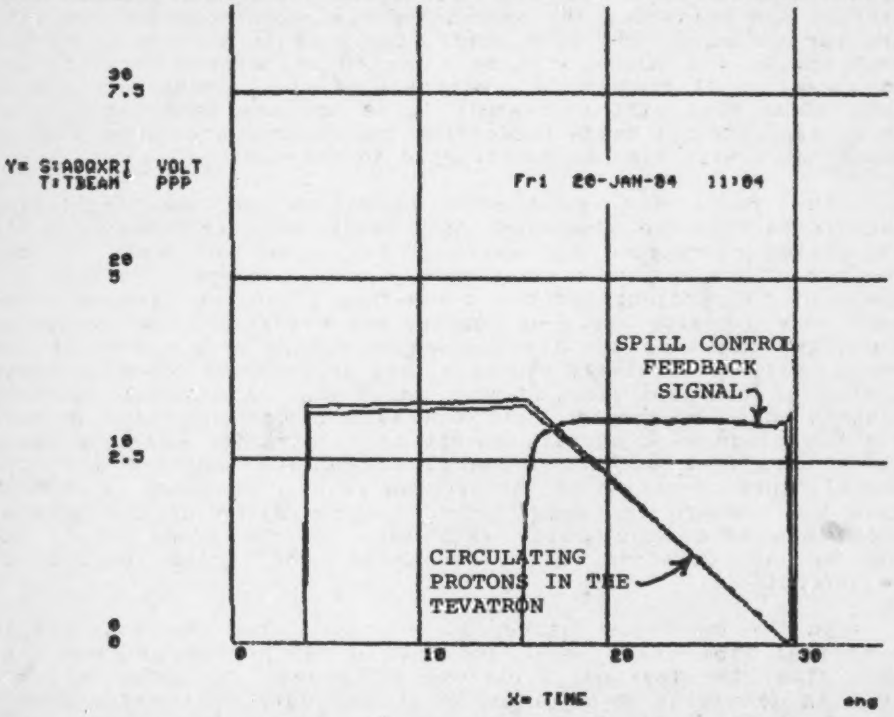
The rapid and successful operation of the facilities associated with the superconducting Tevatron accelerator, and its associated extraction and switchyard systems bode well for the success of the entire fixed-target physics program. So far, the goals of the project and the fixed-target program have been met in a very pleasing way. Of course, not everything has proceeded smoothly. This is the first superconducting accelerator in the world, and it was always expected that there would be an extended period of commissioning, during which the many novel Tevatron systems could be proved. The expectation certainly came to pass and has produced a certain amount of frustration and impatience among the first users. Already, however, a smoother and more satisfactory operation of the program is in place, and if we look back and compare the duty factor for operation of the present superconducting accelerator with that of its predecessor, the improvement obtained has been well worth the period of adjustment.

In the immediate future, the energy of the accelerator will be raised from its present 400 GeV to 700 GeV or greater. At this time, the Tevatron will come fully into its potential, not only in providing a superior spill and duty factor for fixed-target physics, but in increasing the energy by a factor of 2 over the old Main-Ring capability. Experimenters in all three of the operating areas are looking forward to initial operation at the higher energy with a great deal of anticipation and with high hopes for rapid success. It is the feeling of the people who operate the accelerator that these hopes will be justified and that it will soon be operating routinely in the full Tevatron mode.

Extraction

The first area to be completed in the Tevatron II project was the slow resonant-extraction system for extracting beam from the superconducting accelerator and directing it into the Switchyard. Critical to the extraction success was the development of greatly improved wire septa for splitting off the beam that leaves the accelerator from the beam that continues circulating (and doing this in a controlled manner that minimizes losses in the process).

In the graph below, the result of careful work and planning for the slow-extraction system is seen. The beam from the superconducting accelerator is extracted smoothly and uniformly over a



Slow beam extraction from the superconducting Tevatron accelerator. The traces show two successive cycles of the accelerator. One pair shows beam being spilled uniformly over a 15-second period. The second pair shows the feedback signal that controls the beam spill rate.

15-second period! What cannot be seen from this figure is the modulation of the beam intensity at higher frequencies, such as 60, 180, and 360 Hz, etc. In the initial operating stages, various frequency modulations on the intensity of the beam spill were seen. This modulation is a normal consequence of starting up a new system. Over a period of two months, most of the modulation was removed through various technical means. The spill is now quite smooth and satisfactory to all the experimental areas.

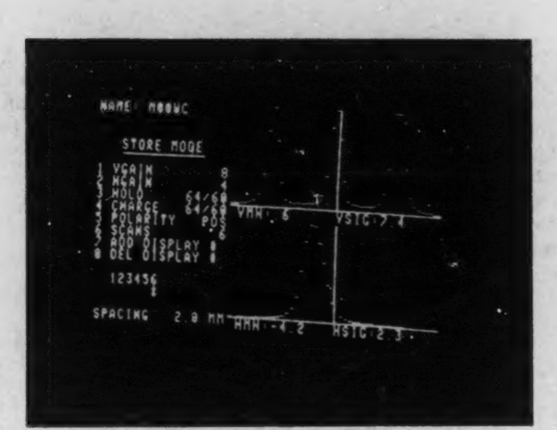
Switchyard

Once the beam leaves the accelerator, it passes into the Tevatron switchyard area where electrostatic splits divide the beam into multiple primary beams that continue on to production targets for the various experiments. The largest project in the Tevatron switchyard was the superconducting right bend to the Proton Area. This project, completed during the long 1983 accelerator shutdown, has two strings of superconducting Energy-Saver dipoles that take the beam split off to the Proton Area by the electrostatic and magnetic septa and bend it sharply to the East.

After passing through the superconducting right bend, the Proton primary beam is again split into three parts. The three primary beams in the Proton Area are subsequently targeted independently for the P-East, P-Center, and P-West beams. In Phase Two of the Tevatron, the P-East beam will pass through yet another electrostatic split, allowing photon beams to be used simultaneously in the Tagged Photon Laboratory and in the new Wide Band Neutral Beam. The primary beam transport for all parts of the Proton Lab are now complete except for the two-way split to the Wide Band target. The Wide Band split will be installed during the summer 1984 shutdown.

The primary beam to the Meson Area passes through the superconducting left bend which was installed prior to the Tevatron II Project. Once through the left bend, the Meson primary beam is split into three parts, as in the Proton area (see top of next page). The three primary beams pass through the old Meson target box and are focused on new targets in the former Meson Detector Building, henceforth to be known as the Meson Target Building.

Work in the Neutrino switchyard area has been relatively low key so far, but there will soon be a significant increase in activity with the installation of an electrostatic split and a superconducting bend that will split off primary beam to the new muon-production target. Construction of components for the muon split is presently underway and the equipment will be installed during the summer of 1984.



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STORE MODE
1 VGAIN           8
2 HGAIN           4
3 HOLD        64/60
4 CHARGE      64/60
5 POLARITY      POS
6 SCANS           6
7 ADD DISPLAY 0
8 DEL DISPLAY 0

  123456
       1

SPACING   2.0 MM
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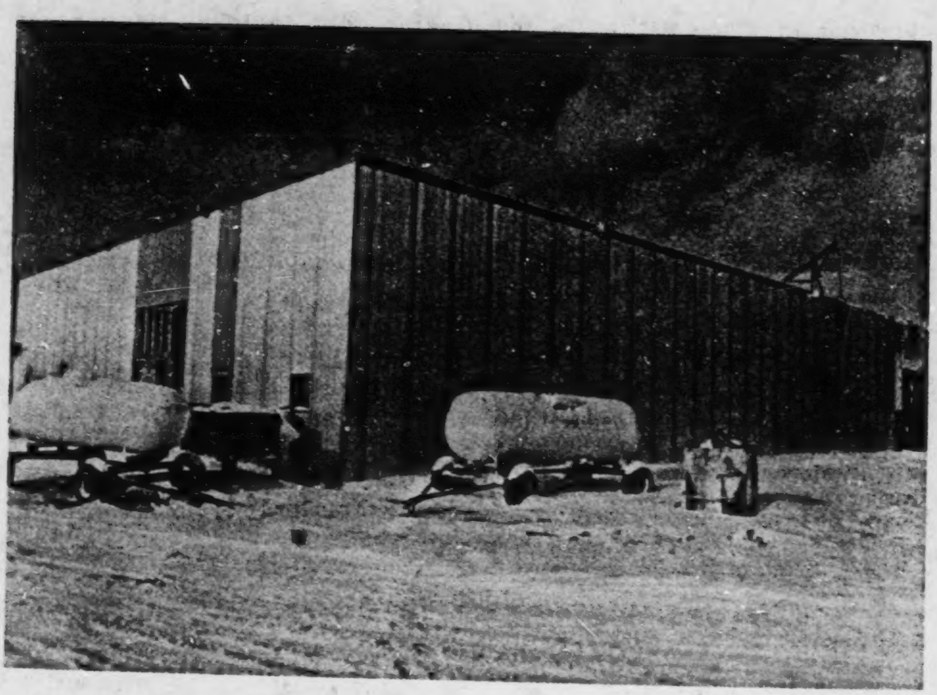
Primary beam SWIC traces after the Meson triple split septa. The beams are clearly separated in the vertical direction, but have not yet been bent apart horizontally by the Lambertson septum magnets.

Current Activities

Currently, the areas of maximum activity in the Tevatron II project involve construction of new experimental halls for the Phase II physics program (experiments in the new particle beams). Lab F, the first of these laboratories, has been under construction since July; it will be complete about March 1 (next page). At that time, experiment E745 will begin to install their equipment, the largest part of which consists of a large heavy-liquid bubble chamber with holographic optics. The bubble chamber and its associated spectrometer will later be used for E636, an experiment to study production of tau leptons and other phenomena in the Prompt Neutrino Beam.

Two new experimental halls will start construction in February and March. These are the new Muon Laboratory and the Wide Band Experimental Hall. Both of these buildings are major structures that will each house two experiments in tandem. Construction of these buildings is hoped to be complete by the Fall of 1984 in order to allow installation of experimental apparatus to be used in testing and shakedown runs in the spring of 1985 for E640, E665, and E687.

Two more large experimental halls are planned for construction in the Meson Area. These experimental laboratories (MP and MW) will house, respectively, the polarized-proton experiment E704 and a new multiparticle hadron spectrometer to accommodate E672 and E706. The design phase of these buildings has begun and it is expected that the construction will commence early in fall of 1984.



A view of the new Lab F experimental hall in the Neutrino Area. This structure will be complete in March 1984.

In parallel with design and construction of the experimental halls, there has been a large amount of design effort for civil structures that will house the secondary-beam elements. In particular, there are eighteen small quadrupole enclosures needed for the new Muon Beam and two extended tunnel enclosures in the Wide Band Beam. Two long surface tunnel enclosures are also needed to house beam-line components in the M-West and Polarized Proton Beams in the Meson Area.

In parallel with the civil facilities being designed and constructed to house the new beams and experiments, a strong coordinated effort is going ahead to construct magnets, beam dumps, controls, and other technical components that will go into these facilities.

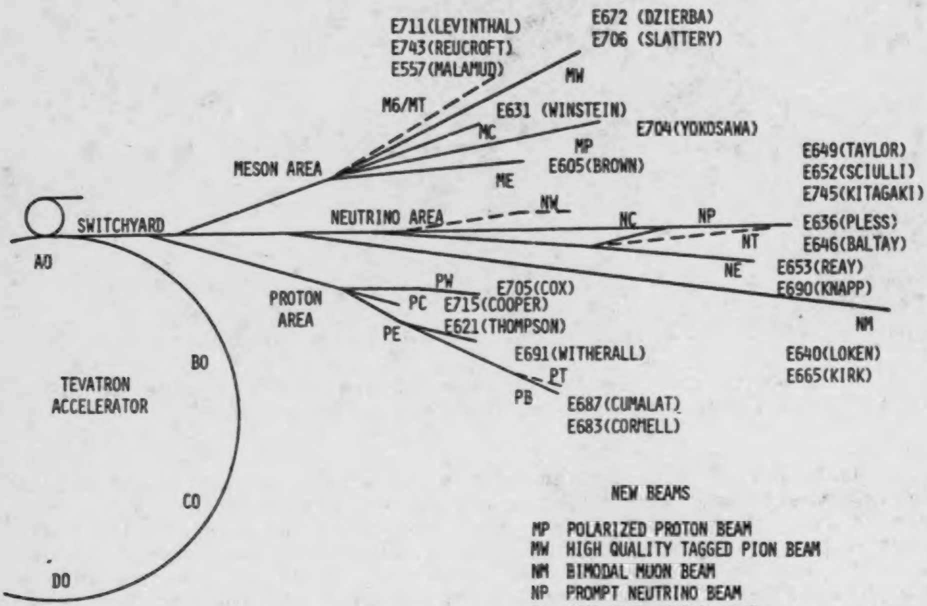
Physics!

When it all comes together in 1985, the TeV II physics program will be fully deployed and Fermilab will resume its role as peerless world leader for fixed-target physics through the

80's and into the 90's. In the diagram that follows, the current array of approved fixed-target experiments for the Fermilab program is shown in reference to the site topology. From hyperons to muons, from neutrinos to antiprotons, from pions to photons, the Fermilab community can look forward to a rich and productive decade of physics ahead.

And it's starting NOW!

TEVATRON II EXPERIMENTS


E711(LEVINTHAL)
E743(REUCROFT)
E557(MALAMUD)
E672 (DZIERBA)
E706 (SLATTERY)
MW
M6/MT
E631 (WINSTEIN)
MC
E704(YOKOSAWA)
MP
E605(BROWN)
MESON AREA
ME
E649(TAYLOR)
E652(SCIULLI)
E745(KITAGAKI)
NW
NEUTRINO AREA
NC
NP
E636(PLESS)
E646(BALTAY)
NT
SWITCHYARD
AO
NE
E653(REAY)
E690(KNAPP)
PW
E705(COX)
PROTON AREA
PC
E715(COOPER)
E621(THOMPSON)
PE
NM
E691(WITHERALL)
E640(LOKEN)
E665(KIRK)
BO
PT
TEVATRON ACCELERATOR
PB
E687(CUMALAT)
E683(CORMELL)
CO
DO

NEW BEAMS

MP	POLARIZED PROTON BEAM
MW	HIGH QUALITY TAGGED PION BEAM
NM	BIMODAL MUON BEAM
NP	PROMPT NEUTRINO BEAM
PB	WIDE BAND NEUTRAL BEAM

WEEK	Avg/pulse for HEP (x E12)	Scheduled HEP Hours	Actual HEP Hours	Number of Quenches	Quench Recovery Time	Total[1] Systems Downtime	Total[1] TEV Downtime	CHL Downtime	Total[2] Non-overlap Downtime
10/3 - 10/9/83	2.29	96.0	35.55	15	8.00	60.93	31.37	6.82	55.15
10/10 - 10/16	2.72	96.0	16.58	7	4.74	182.70	76.51	0.00	125.23
10/17 - 10/23	0.88	168.0	28.86	1	0.40	181.80	108.65	0.00	138.77
10/24 - 10/30	0.00	169.0	0.00	0	0.00	157.50	155.80	0.00	169.00
10/31 - 11/6	3.76	168.0	79.63	29	13.32	93.65	73.77	0.00	85.33
11/7 - 11/13	3.77	96.0	75.22	18	12.18	41.25	28.12	0.00	37.14
11/14 - 11/20	3.53	96.0	54.05	16	9.20	63.31	29.41	0.00	56.31
11/21 - 11/27	5.08	120.0	75.73	25	12.09	83.93	57.94	1.30	70.92
11/28 - 12/4	4.82	96.0	51.98	31	15.21	74.47	57.76	0.00	60.05
12/5 - 12/11	3.51	88.0	10.02	36	13.87	117.90	74.29	4.27	98.94
12/12 - 12/18	4.60	143.25	92.69	17	11.28	67.62	41.55	0.00	53.90
12/19 - 12/25	3.51	72.0	38.08	6	1.94	36.73	24.51	0.00	49.08
12/26 - 1/1/84	3.24	132.0	51.38	8	3.94	87.04	55.61	8.92	69.82
1/2 - 1/8	4.65	106.0	62.29	20	21.68	68.73	49.55	7.78	57.47
1/9 - 1/15	6.64	132.0	94.22	13	6.69	43.53	30.48	0.00	30.48
1/16 - 1/22	7.41	137.0	83.35	7	2.73	61.21	24.99	21.15	50.79
1/23 - 1/29	7.91	144.0	118.39	7	2.18	37.24	16.93	0.00	31.90
1/30 - 2/5	5.39	136.0	60.91	4	1.84	85.93	29.89	3.85	72.70

1) Does not have overlap of simultaneous downtimes subtracted out. Does not include tuning time.

2) Does have overlapping downtimes subtracted out. In cases where this is larger than total systems downtime, it means there were conflicting amounts of tuning time between my two sources.

WEEK	Cryogenic Downtime	TEV/Total[3] Downtime (%)	Quench/Total[4] Downtime (%)	Quench/TEV[5] Downtime (%)
10/3 - 10/9/83	11.75	51.5	13.1	25.5
10/10 - 10/16	13.07	41.9	2.6	6.2
10/17 - 10/23	0.00	59.8	0.2	0.4
10/24 - 10/30	0.00	98.9	0.0	0.0
10/31 - 11/6	1.84	78.8	14.2	18.0
11/7 - 11/13	2.43	68.2	29.5	43.3
11/14 - 11/20	5.77	46.4	14.5	31.3
11/21 - 11/27	10.04	69.0	14.4	20.9
11/28 - 12/4	12.94	77.6	20.4	26.3
12/5 - 12/11	35.34	63.0	11.8	18.7
12/12 - 12/18	8.03	61.4	16.7	27.1
12/19 - 12/25	8.72	66.7	5.3	7.9
12/26 - 1/1/84	15.55	63.9	4.5	7.1
1/2 - 1/8	12.21	72.1	31.5	43.8
1/9 - 1/15	9.93	70.0	15.4	21.9
1/16 - 1/22	5.40	40.8	4.5	10.9
1/23 - 1/29	3.32	45.5	5.8	12.9
1/30 - 2/5	14.91	34.8	2.1	6.2

3) Column 7 divided by column 6 (on previous page).

4) Column 5 divided by column 6 (on previous page).

5) Column 5 divided by column 7 (on previous page).

NEWS FROM THE ENERGY SAVER

The major objective of the Energy Saver in the last several months has been to run at 400 GeV for the high-energy physics program with as high an intensity and reliability as possible. The Accelerator Division has worked hard to make this possible. There has also been a considerable amount of work directed toward solving problems in a longer time interval. This article will discuss a small part of this longer-range effort.

Reliability

One thing that was learned last time on the Main Ring was that detailed information on the frequencies and causes of failures is a necessary condition for improving reliability. We are now collecting such information in considerable detail. Frank Turkot and Duane Plant are working on this program. The accompanying tables are a summary of down times in the accelerator system.

The period October through January was the first four months of operation for the Tevatron. There were 2,200 hours of scheduled HEP and 1,039 actual hours delivered to at least one experimental area between October 3, 1983, and February 5, 1984. Major losses of operating hours were suffered during three weeks in October when a failure of the quench-protection system made it necessary to replace three damaged spool pieces. At about the same time, a broken water pipe kept the rf systems off for a considerable time. There were two power failures in December and one in January. The January failure was sitewide. The bad weather at the end of December interrupted nitrogen deliveries, all of which resulted in bad operating weeks. The bar graphs on the next page show reliability and down time in this period.

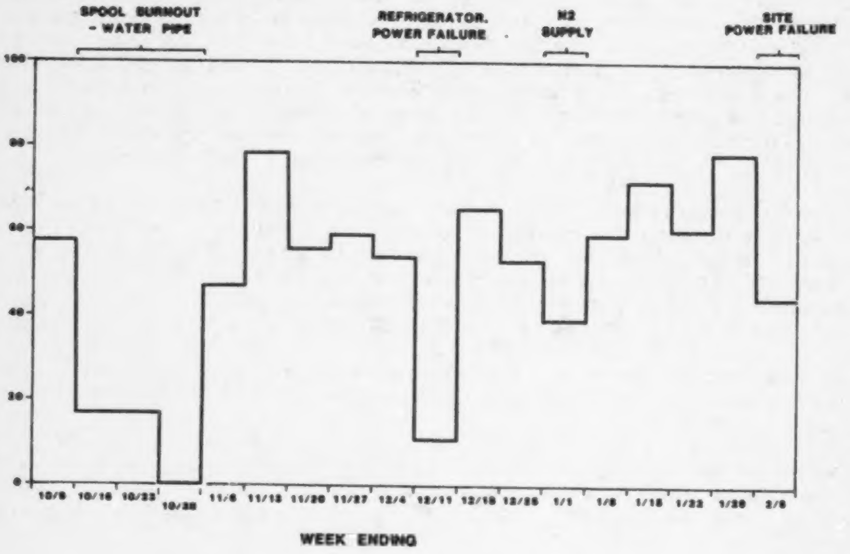
Typical operation is 60% of scheduled whereas it was about 80% before the turn off of the Main Ring for Energy Saver installation. Continual work will be required to get back to higher reliability.

Orbits

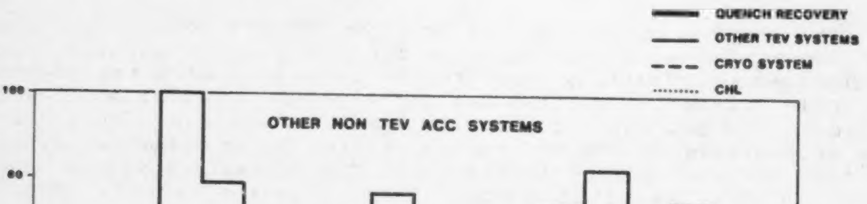
The ORBIT program described in these pages (October 1983) by Rajendran Raja has been used extensively to correct orbits to very small (<1 millimeter) deviations. It is worth noting that the orbit correction depends not only on ORBIT, but on the beam-position monitor (BPM) system designed and built by Bob Shafer and on the correction-magnet system.

Previous BPM systems have only been able to measure closed orbits--the sum over many turns. The Energy Saver BPM can measure positions of either closed orbits or single turns.

PERCENT OF SCHEDULED HEP



TEV PERCENT OF TOTAL DOWN TIME



Previous orbit correction at high fields has been done by realigning magnets; it has never been possible to provide a completely corrected orbit because of the time required to align magnets over the large distances of our accelerator. Realignment as a method for orbit correction is not feasible in the Energy Saver, because of the complicated cryogenics plumbing at the ends of the quadrupoles. Instead, the Energy Saver has a correction-magnet system that will move the beam across the chamber even at 1 TeV. In addition, the system has programmable waveform generators that give the capability of correction at all energies.

The accompanying plots show some recent results for the first turn and for the closed orbit at injection. In the first-turn plot (labelled FLASH FRAME) the horizontal positions at E11, E13, and E15 are set as prescribed for injection. The kicker at E17 kicks the first turn on to a centered path. There is a shorted horizontal correction coil at E26 and centering is not possible. In both horizontal and vertical, the positions at A0 and D0 are set to move the beam around extraction devices. The non-zero positions at D48 and D48 are part of the orbit-closing process.

In the closed-orbit plot (DISPLAY FRAME) the differences from the first turn are that horizontally E11 is now set to avoid the injection Lambertson and E15 is dictated by the closure process.

Studies

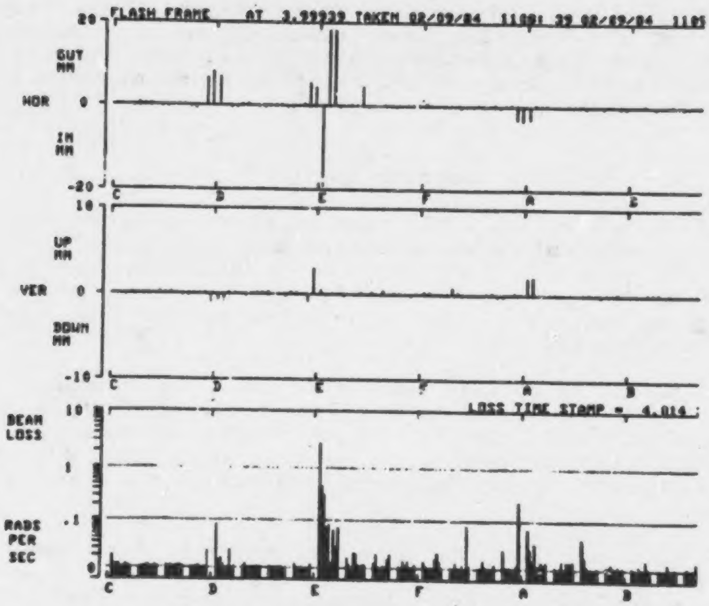
As part of the national effort on the design of the Superconducting Super Collider (SSC), many accelerator studies have been done. Rolland Johnson has summarized this effort.

The primary purpose of the Tevatron for the present and the next two years is to provide beams for fixed-target physics. As a consequence, virtually all studies have been directed toward the goals relevant to extraction and high-intensity fixed-target physics. The present situation is that low-intensity beams have been accelerated to 700 GeV and extraction to experimental areas has been accomplished up to 512 GeV. The present operating mode is at 400 GeV, about 10^{13} ppp, 15-sec flat-top, with a 39-sec cycle.

Some data from the commissioning of the fixed-target program are particularly relevant to the SSC, even if the SSC is not used for fixed-target physics. These data are mostly to answer the question "How predictable is/was the Tevatron?"

Collider

In 1983, there were three sessions of coasting-beam studies. These were directed towards the development of storage techniques and to get a first look at the Tevatron as a collider. Indeed, the techniques were quickly implemented and the initial coasting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OUT MM
HOR 0
IN MM
-20
C
D
E
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A
B
10
UP MM
VER 0
DOWN MM
-10
C
D
E
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A
B
LOSS TIME STAMP = 4.014
BEAM LOSS
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1
RADS PER SEC
.1
0
C
D
E
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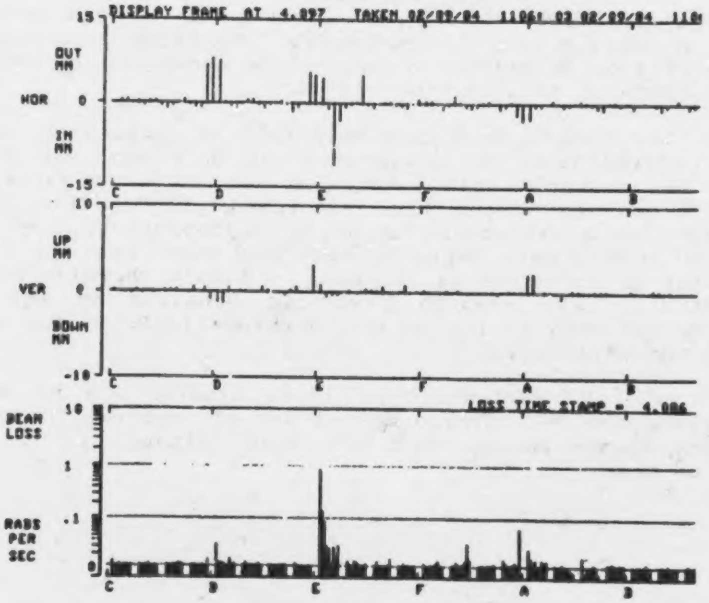
A
B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OUT MM
HOR 0
IN MM
-15
C
D
E
F
A
B
10
UP MM
VER 0
DOWN MM
-10
C
D
E
F
A
B
LOSS TIME STAMP = 4.086
BEAM LOSS
10
1
RADS PER SEC
.1
0
C
D
E
F
A
B

beam studies at 400 GeV were very encouraging. The transverse stability of the coasting beam seems to be very good at low intensity, with long lifetimes (> 24 hours) even on potentially strong resonances. Longitudinal dilution seems to occur rapidly, and may need individual bunch damping.

Machine Studies

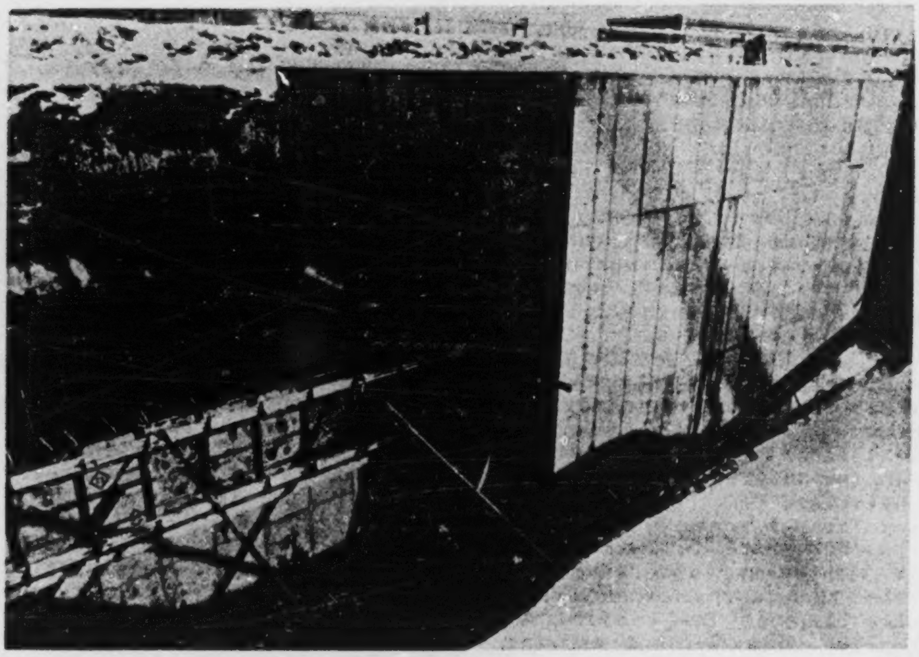
In 1983, there were two machine study sessions devoted to the dynamic range of superconducting magnets. These studies are particularly relevant for HERA, which will have an injection energy of 40 GeV and a top energy of 820 GeV, more than a factor of 20 higher. As well, the magnets and lattice are similar to the Tevatron design.

For the SSC to operate between 1 and 20 TeV implies that the Tevatron should certainly have a reasonably good field aperture from 50 GeV to 1 TeV. Details of SSC magnet construction such as bore diameter and filament size, as well as lattice design, make the measurements described here relevant, but not directly scaleable.

For these studies, the beam was injected into the Tevatron at the normal 150 GeV Main-Ring energy and then decelerated. This technique has several advantages over trying to inject directly at 50 GeV. First, it isn't necessary to change anything in the Main Ring itself or in the MR to Tevatron transfer system. Second, by starting from a known set of operating conditions the beam can be decelerated in a more controlled fashion in small steps, if necessary. The major disadvantage of the deceleration technique is that it is necessary to understand the hysteresis of the Tevatron magnets.

Detailed studies have also been done to compare the betatron tunes predicted from the measured field data with the measured tunes. The measured values of 19.6 and 19.2 horizontally and vertically differ from the predicted 19.4. This can be interpreted as a systematic error of approximately 1 mm in the sagitta of the dipole magnets when they were bent to have the same radius of curvature as the beam, although there is as yet no confirmation. The average sextupole behavior of the dipole magnets corresponds to the predicted chromaticity of the machine, although not perfectly.

The general conclusions of these studies are by no means discouraging for SSC. There are plenty of problems to be worked on in the Energy Saver, but they look solvable to the people working on them.



Construction of the Target Station for TeV I.
(Photograph by Fermilab Photo Unit)

1984 SNOWMASS SUMMER STUDY

John Peoples, Chairman of the Division of Particles and Fields of the APS, has announced plans for the Snowmass Summer Study scheduled to take place June 23-July 13 at Snowmass, Colorado. The meeting is to be devoted to the design and utilization of the SSC. Attendees will work toward defining the properties of the SSC machine, as well as the experimental environment including test beams and discuss the physics opportunities of the SSC and how they impact the machine design. The Snowmass meeting will be the culmination of the various workshops being held around the country.

The attendance at the Snowmass summer study will have to be restricted to roughly 250 physicists because of the size of the facilities, but the meetings are open and are intended to have a broad participation from all the Users' Groups in the U. S. Preference will be given to those attending the full three weeks. Peoples made a special note of the intent to include younger physicists in the meetings and he mentioned that there may be some travel money for them.

This year's meeting will be organized somewhat differently from the last Snowmass meeting. Peoples expects that roughly one-third of the conference will be devoted to joint sessions hearing speakers and two-thirds to working on various specific topics. These topics will be the test of the standard model, pp, $\bar{p}p$, fixed target, accelerator properties, optics, test beams, and a set of more specialized topics defined by the physics. There will be a small library and, it is hoped, better computing facilities than were available in 1982. Announcements will be sent out in mid-February.

A range of accommodations for the sessions will be available. Joanne Day of Argonne National Laboratory is organizing the accommodations. Interested individuals should contact her (312) 972-6181.

Light pipes for the CDF central hadron calorimeter being fabricated at Frascati.

(Photograph by Fermilab Photo Unit)

MANUSCRIPTS, NOTES, LECTURES, AND COLLOQUIA PREPARED OR PRESENTED FROM JANUARY 23, 1984 TO FEBRUARY 19, 1984

Copies of preprints with Fermilab publication numbers can be obtained from the Publications Office or Theoretical Physics Department, 3rd floor east, Central Laboratory. Copies of some articles listed are on the reference shelf in the Fermilab Library.

Experimental Physics

D. E. Wagoner et al. Experiment #705	A Measurement of the Energy Resolution and Related Properties of an SCG1-C Scintillation Glass Shower Counter Array for 1-25 GeV/c Positrons (FERMILAB-Conf-84/21-E; submitted to the 1983 Nuclear Science Symposium, San Francisco, October 19-21, 1983)
R. Rameika et al. Experiment #705	Measurement of Electromagnetic Shower Positions and Size with a Saturated Avalanche Tube Hodoscope and a Fine Grained Scintillation Hodoscope (FERMILAB-Conf-84/22-E; submitted to the 1983 Nuclear Science Symposium, San Francisco, October 19-21, 1983)
B. Cox et al Experiment #705	A Measurement of the Response of an SCG1-C Scintillation Glass Array to 4-14 GeV/c Pions (FERMILAB-Conf-84/23-E; submitted to the 1983 Nuclear Science Symposium, San Francisco, October 19-21, 1983)

Theoretical Physics

A. Sen	A Locally Supersymmetric SU(6) Grand Unified Theory Without Fine Tuning and Strong CP Problems (FERMILAB-Pub-83/106-THY; submitted to Nucl. Phys. B)
S. Fajfer and R. J. Oakes	Twist-Four Effects on the Asymmetry in Polarized Electron Deuteron Scattering and $\sin^2\theta_W$ (FERMILAB-Pub-84/16-T; submitted to Phys. Rev. D Brief Notes)

T. R. Taylor	Stability of Supersymmetric Ground State in Chiral Theories (FERMILAB-Pub-84/20-T; submitted to Phys. Lett. B)

Astrophysics

M. S. Turner	Particle Physics and Cosmology: The Inner Space/Outer Space Connection (FERMILAB-Conf-83/109-AST; summary of invited talk given at the APS Division of Particles and Fields Meeting, Blacksburg, Virginia, September 1983)
P. J. Steinhardt and M. S. Turner	A Prescription for Successful New Inflation (FERMILAB-Pub-84/19-A; submitted to Phys. Rev. D)

General

M. Fischler and T. Nash	Computing Tools for Accelerator Design Calculations (FERMILAB-Conf-84/18; submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)
J. F. Bartlett et al.	The EPICS System: An Overview (Submitted to the Digital Equipment Computer User Society, Las Vegas, October 1983)
T. E. Lahey et al.	EPICS System: RSX Implementation Issues (Submitted to the Digital Equipment Computer User Society, Las Vegas, October 1983)
R. E. West et al.	EPICS System: System Structure and User Interface (Submitted to the Digital Equipment Computer User Society, Las Vegas, October 1983)

N. M. Gelfand	Calculations of the Dynamic Aperture at the Tevatron (Submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)
L. Teng	Design Considerations and Procedures for the SSC (Submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)

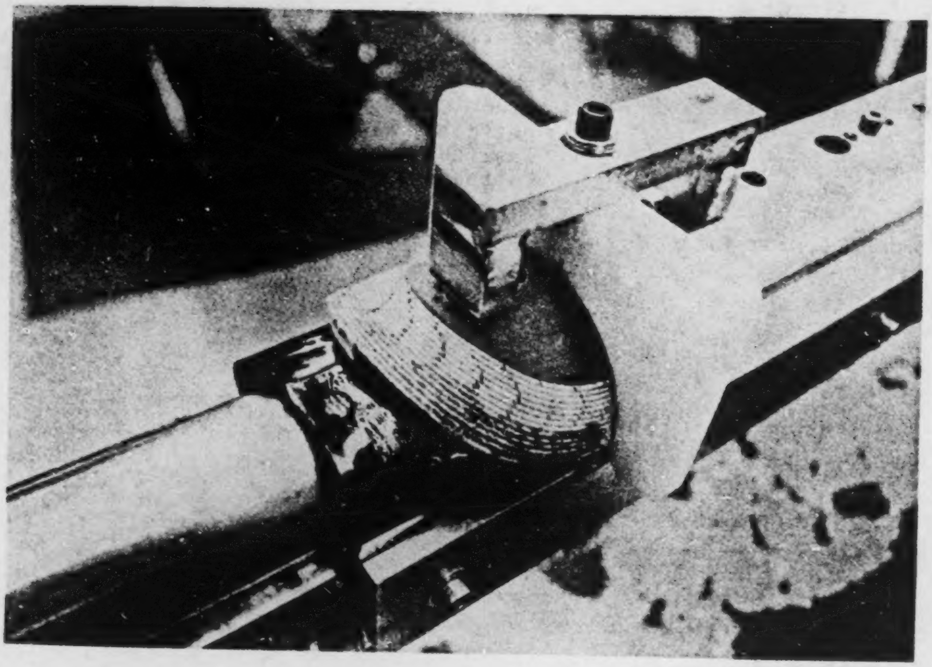
Physics Notes

R. A. Carrigan	Particle-Cosmology Desk Companion (FN-395)
R. P. Johnson	The Tevatron as an SSC Prototype: Experience Versus Predictions (FN-396; submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)

Colloquia, Lectures, and Seminars

H. Thacker	"Lattice Gauge Theory of Quarks and Gluons" (Fermilab, January 30 and February 1, 1984)
H. Casebolt	"Antiproton Source Safety System" (Fermilab, February 2, 1984)
J. Hangst	"Pulsed Magnet for Antiproton Target Station" (Fermilab, February 2, 1984)
S. Love	"Introduction to Supersymmetry (SUSY)" (Fermilab, February 6, 8, 13, and 15, 1984)
J. McCarthy	"Preliminary Report on Power Supply Procurement" (Fermilab, February 9, 1984)
A. Moretti	"Status Report on the Debuncher Cavity" (Fermilab, February 9, 1984)

R. Orr	"Accelerator Division Informations Meeting" (Fermilab, February 14, 1984)
M. Kuchnir	"The Chicago/Fermilab/Michigan Magnetic Monopole Detectors" (Illinois Institute of Technology, Chicago, February 15, 1984)



Coil of a 2-in. superconducting dipole prototype.
(Photograph by Fermilab Photo Unit)

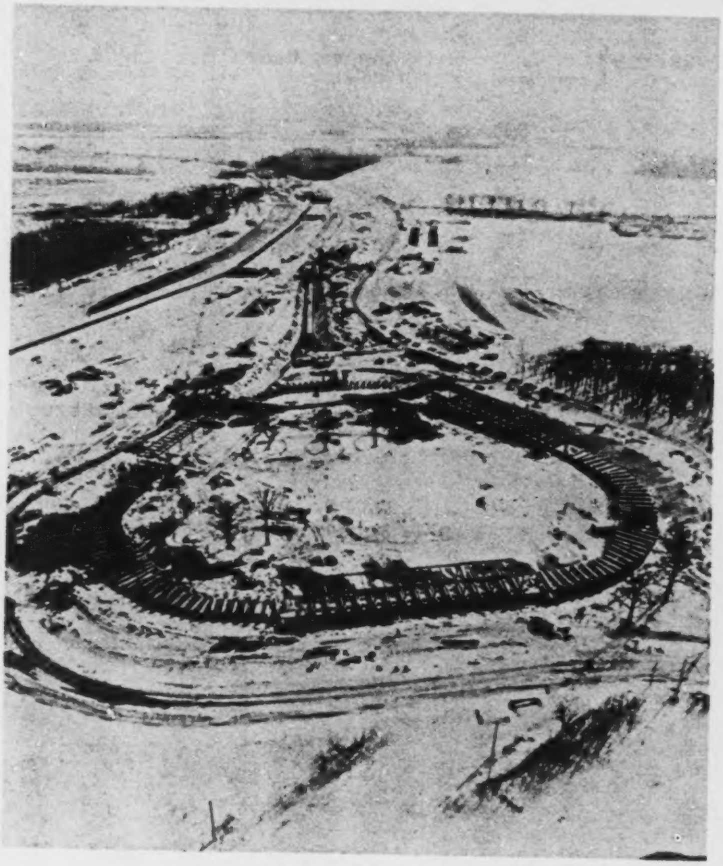
DATES TO REMEMBER

March 1, 1984	Deadline for submission of material for consideration by the Physics Advisory Committee at the June meeting
April 19-20, 1984	PAC Proposal Presentation Meeting
April 27-28, 1984	Annual Users Meeting
April 28, 1984	Dedication Ceremony, Energy Saver
May 2-4, 1984	"Inner Space-Outer Space," Workshop on High-Energy Physics, Astrophysics, and Cosmology
June 16-22, 1984	Extended Summer Meeting of the Physics Advisory Committee
August 13-24, 1984	U. S. Summer School on Particle Accelerators, Fermilab

fermilab report

Fermi National Accelerator Laboratory Monthly Report

March 1984



RADIATION MEASUREMENTS AT FERMILAB

S. Baker, D. Cossairt, L. Coulson, A. Elwyn, and P. Yurista

Introduction

Radiation associated with the production and utilization of high-energy particles at Fermilab has been extensively monitored and has been the subject of several detailed studies. Measurements have been made for assurance that radiation protection is adequate for ourselves and our neighbors. Radiation damage and heating of components have been investigated to ascertain that the accelerator and experimental areas will continue to operate reliably. Finally, there has been the continual refinement of radiation measurements for instrument calibration and efficient shielding design.

Radiation Protection

Most of the radiation measurements at Fermilab have been for radiation protection of personnel. Besides the routine monitoring of accelerator operations and environmental releases, there have been a number of studies comparing measured radiation dose rates and radioactivation with those calculated using models of particle interactions with matter. The most frequently used computer program at Fermilab for these calculations is CASIM, written by Andreas Van Ginneken.[1] It traces the interactions of incident high-energy hadrons and the cascades of secondary particles resulting from the primary interactions. This program is utilized in the design of shielding for beam-transport lines, targets, and beam dumps. Since personnel protection and shielding costs depend on such designs, there is a strong impetus to check the capabilities of this program.

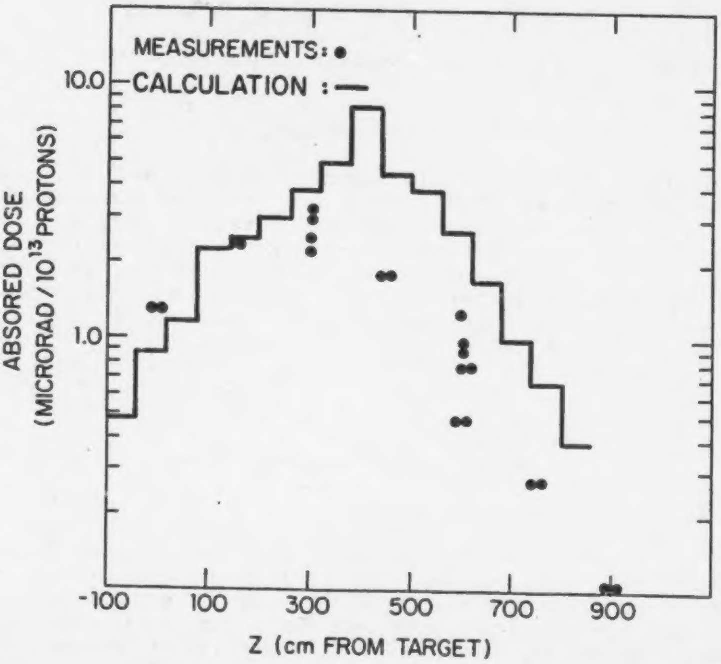
The three principal studies which have been done for comparing CASIM results with **in situ** radiation measurements are

1. Absorbed dose measurements outside thick shields of various compositions.[2]

2. Hadron cascade development.[3]

3. Absorbed dose measurements close to a target inside a magnet.[4]

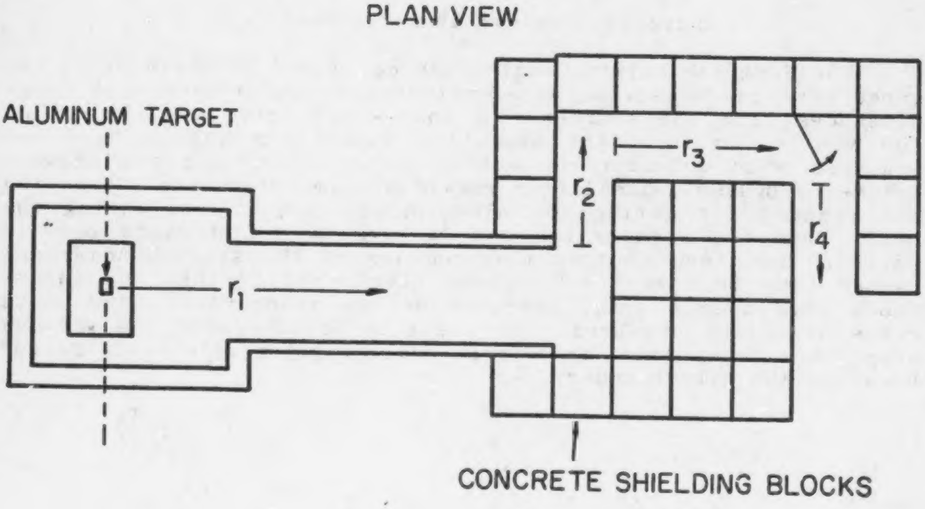
Typical of the thick shielding studies was a recent set of measurements outside a seven meter (23 ft) thick soil shield.[2] The proton beam was directed onto a long iron rod target inside the shielded underground beam enclosure. Measurements were made at ground level above the enclosure. The soil attenuates the radiation ten million times. CASIM predicts this 10^7 attenuation to within a factor of three of the measured values.



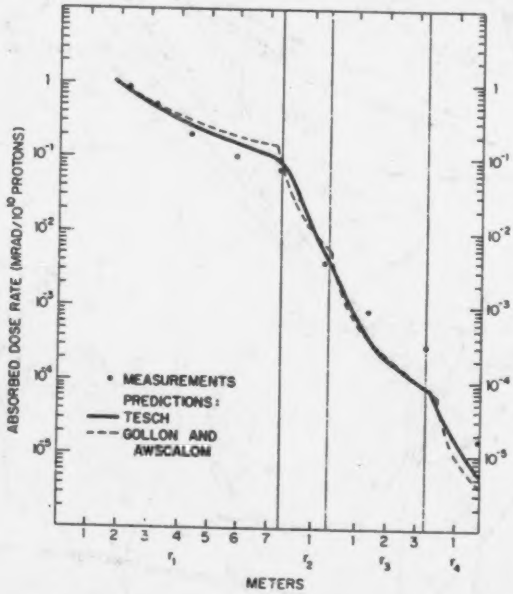
Comparison of predictions with radiation measurements outside a thick soil shield.

Similar studies for thin shields were performed earlier (E-108 and E-321) with similar results. The first experiment investigated the development of the hadronic cascade in aluminum, steel, and lead. Besides checking the CASIM program, it was useful for development of hadron calorimeters for high-energy physics experiments. The latter experiment investigated the radiation produced by protons striking a target inside a magnet. It yielded information on dose rates for radiation workers, as well as a comparison between Fermilab and CERN computer programs.

Recently, measurements were made in a labyrinth used for entrance into a beam enclosure at Fermilab. Neutron attenuation in labyrinths is an important consideration in the design of high-energy proton accelerator enclosures both from personnel protection and cost efficiency viewpoints. The initial physics run of the Energy Saver at 400 GeV just completed presented a unique opportunity to study a particular labyrinth in the Neutrino Area. This accessway viewed a 30-cm long by 20-cm square aluminum target. The results of the measurements were compared to the predictions scaled from the earlier results of Gollon and Awschalom[5] and to the results of the formula of Tesch.[6] The agreement is very good considering the large dynamic range involved.


PLAN VIEW
ALUMINUM TARGET
r_1
r_2
r_3
r_4
CONCRETE SHIELDING BLOCKS

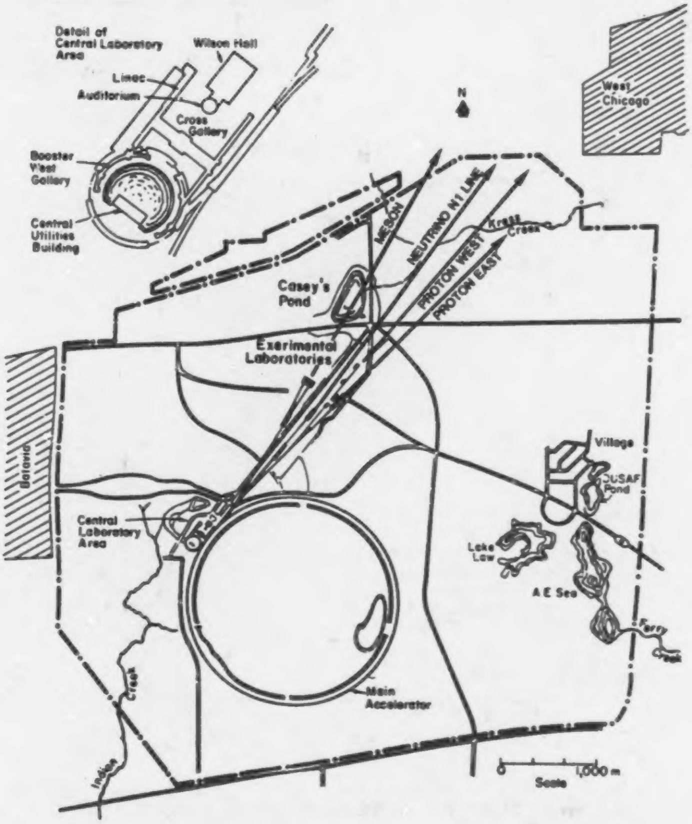
Labyrinth geometry



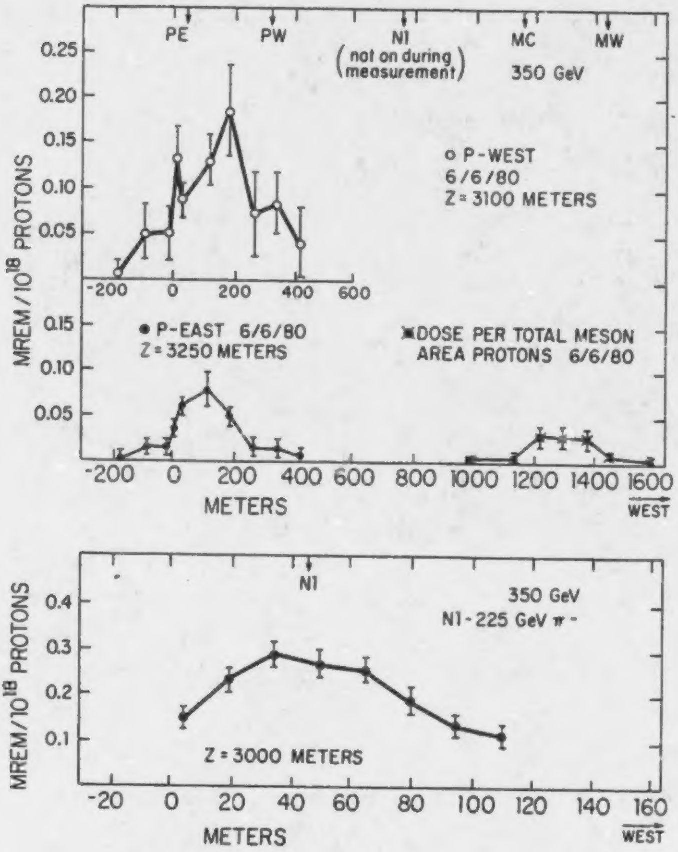
Attenuation of neutrons in a labyrinth.

Radiation Surveys at Large Distances

The Fermilab Safety Section has developed and maintained the capability for measuring accelerator-produced radiation at large distances from the sources. A four-wheel drive vehicle called the Mobile Environmental Radiation Laboratory (MERL) has been equipped with detectors, counting electronics, and a microwave telemetry system. The latter provides beam intensity information and signals for gating the electronics to get data during the spill from the accelerator and background measurements between spills. Muon and neutron measurements at the site boundary and beyond have been made.[7,8] These have verified that the annual doses have been a small fraction of the standards.[9] Muon dose rates have been measured near the site boundary for the various beam lines. The muons are directional, forming relatively narrow beams at the site boundary.


Detail of Central Laboratory Area
Wilson Hall
Linac
Auditorium
Cross Gallery
Booster West Gallery
Central Utilities Building
N
West Chicago
MESON
NEUTRINO N1 LINE
PROTON WEST
PROTON EAST
Kress Creek
Casey's Pond
Exerimental Laboratories
Batavia
Village
DUSAF Pond
Central Laboratory Area
Lake Law
A E Sea
Ferry Creek
Main Accelerator
Indian Creek
0
1,000 m
Scale

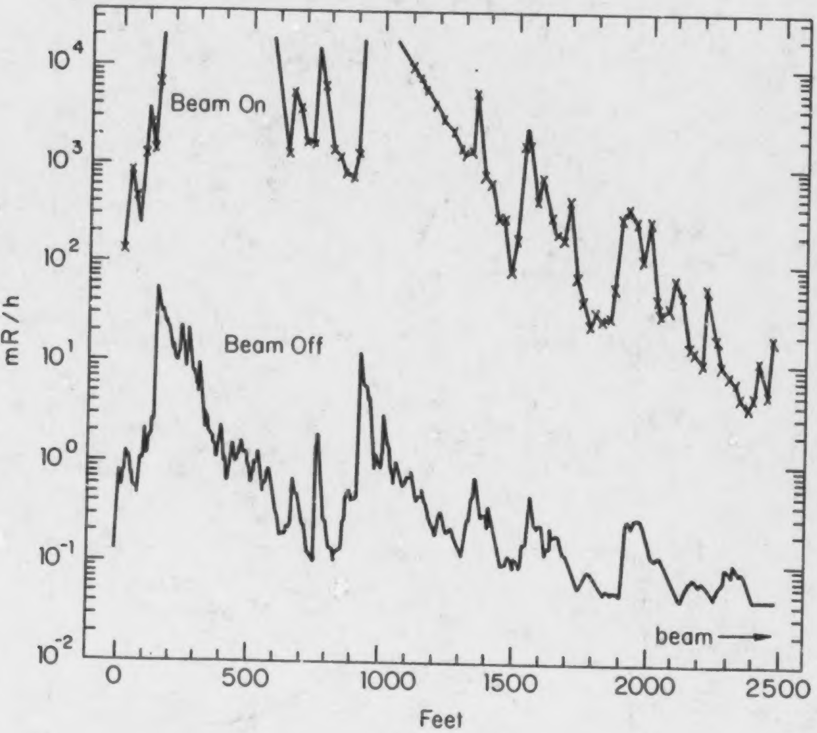
Penetrating radiation (muon) directions.



Muon beams near the site boundary.

Residual Radioactivity

Several studies have been made of residual radioactivity inside the Main Ring and the relationship between accelerator beam on and beam off dose rates.[10,11] The ratio of beam on to beam off rates is typically about 10,000 at locations where the activation has occurred over a relatively short time period. The isotopic production in iron and the rate of decay have been investigated. For a short irradiation, the three manganese isotopes ^{52}Mn, ^{54}Mn, and ^{56}Mn dominate. For the first five hours after the end of the irradiation, ^{56}Mn (half-life 2.6 h) is the most intense radionuclide. For the next 20 days, ^{52}Mn (half-life 5.6 days) is most prevalent. After that, ^{54}Mn (half-life 312 days) provides most of the gamma radiation for many years.

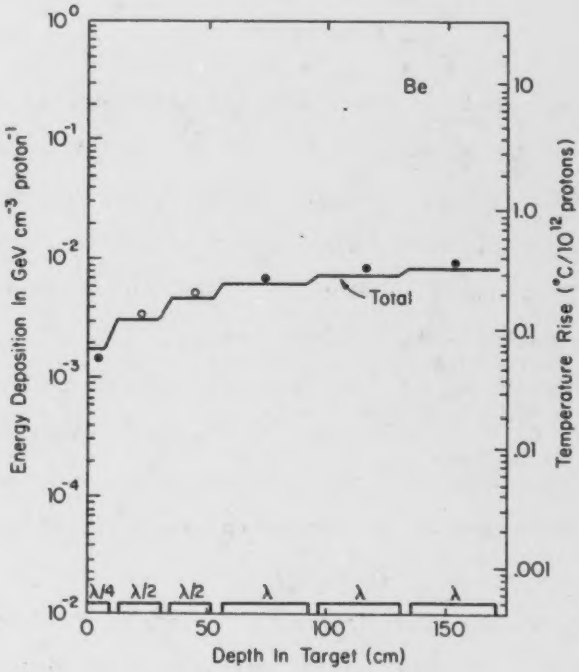


Radiation levels in a section of the Main-Ring tunnel.

Radiation Damage and Heating

The dose response of silicon controlled rectifiers (SCR's) to neutrons from the Neutron Therapy Facility neutron beam has been used to estimate the useful life of the SCR's in the Main-Ring tunnel.[12] These SCR's are now being used for quench protection of the Energy Saver superconducting magnets.

The heating of different target materials by proton interactions was studied as a function of target thickness.[13] These results were compared with calculations carried out using the computer program CASIM. The agreement between calculation and experiment was good. Subsequently, CASIM was used to predict the number of proton interactions at which quenching of the Energy Saver magnets would occur. The results gave reassurance that the Saver magnet quenches could be held to a low frequency, as has been the case.



Energy deposition in a one-inch diameter beryllium target.

Instrument Calibration

The studies verifying the hadron cascade development model used for calorimeter design and calibration have been mentioned above. In addition, a foil-activation technique has been refined at Fermilab for calibrating beam intensity measuring instruments.[14] The cross section for production of ^{24}Na in natural copper has been measured to 3%. The radioactivity in the foils is assayed using a Ge(Li) gamma-ray detector.

Conclusion

The long history of radiation measurements at Fermilab has benefited the Laboratory by verifying that the employees and the surrounding population are properly protected from radiation. In addition, the studies have assisted the Laboratory and experimenters in accelerator operations and instrument calibration. Finally, the publications resulting from these studies have furthered the understanding of radiation physics.

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2. J. D. Cossairt et al., Nucl. Instrum. and Methods **197**, 465 (1982).
3. P. J. Gollon et al., Nucl. Instrum. and Methods **189**, 387 (1981).
4. M. Awschalom et al., Nucl. Instrum. and Methods **138**, 521 (1976).
5. P. J. Gollon and M. Awschalom, CERN Report 71-16, Vol. 2, 1971, p. 697.
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7. J. D. Cossairt, Health Phys. **45**, 651 (1983).
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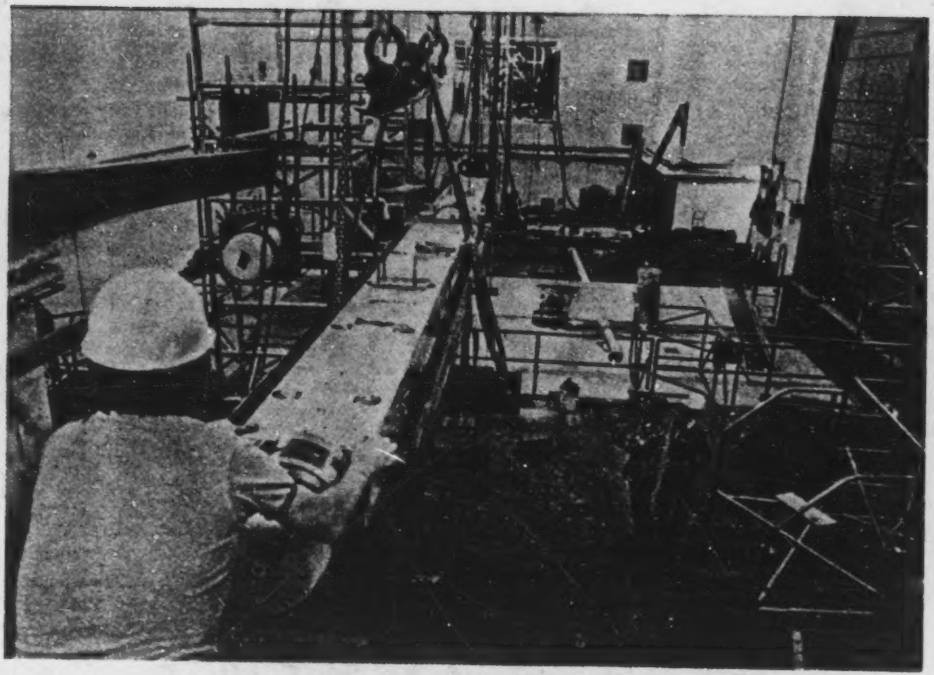
11. J. H. McCrary and D. D. Jovanovic, Particle Accelerators 7, 119 (1976).
12. J. Lockwood et al., Fermi National Accelerator Laboratory Report TM-1094, 1982.
13. M. Awschalom et al., Nucl. Instrum. and Methods **131**, 235 (1975).
14. S. I. Baker et al., Nucl. Instrum and Methods, to be published.

An aerial view of BO and the Industrial Area, with the newly completed Center building. The Central Helium Liquefier is in the background.

(Photograph by Fermilab Photo Unit)



Installation work on the "low-beta" interaction region at B0.
(Photograph by Fermilab Photo Unit)

THE ANN ARBOR SSC WORKSHOP

Charles Ankenbrandt

About a hundred physicists and engineers participated in a workshop on Accelerator Physics Issues for a Superconducting Super Collider (SSC) from December 12-17 in Ann Arbor. Sponsored by the Division of Particles and Fields (DPF) of the American Physical Society and hosted by the University of Michigan, the workshop was organized in response to a call for SSC-related workshops by the HEPAP (High Energy Physics Advisory Panel of the Department of Energy) Subpanel on AARD (Advanced Accelerator Research and Development). The stated purpose of the workshop was "to review the accelerator physics problems involved in the design of an SSC, to describe the methods applicable to these problems, giving examples where appropriate, and to pinpoint gaps in our knowledge and computational design methods which can be closed by further work or must be bridged by conservative assumption." Proceedings of previous DPF-related workshops held in the summer of 1982 in Snowmass, Colorado, and in March of 1983 at Cornell University provided a starting point.

Introductory speakers included Maury Tigner on Workshop Goals and Organization, Jacques Gareyte on S$\bar{p}$pS Performance, Eberhard Keil on CERN Plans for Hadron Colliders, and Albin Wrulich on Particle Tracking in the HERA Proton Ring. Monday afternoon the participants formed six working groups to address the following topics:

1. End Use Parameter-Primary Accelerator Parameter Relationships
   (coordinated by E. Courant and R. Diebold),
2. Lattice and Interaction Region Optics
   (D. Edwards and K. Steffen)
3. Stability Assurance
   (R. Siemann and M. Cornacchia)
4. Aperture Determination
   (R. Palmer and R. Talman)
5. Subsystem Considerations and Requirements
   (H. Halama and G. Lambertson)
6. Beam Cooling
   (T. Collins)

The design of the SSC will involve the choice of major parameters with the goal of maximizing the performance/cost ratio. Although the Ann Arbor workshop was not supposed to produce a design, the first working group, which I joined, examined the relationships among the major parameters. The work of the other groups also bears directly on the choice of parameters. This article presents some of these relationships and outlines coherent ways of thinking about them. Concentrating on parameters provides a convenient framework for this overview; the published proceedings will represent the real summary of the workshop, including the efforts of the other working groups, which receive short shrift here. Caveat: opinions expressed here are mine, but good ideas may well involve plagiarism.

Relationships Among Parameters

The term SSC is usually taken to mean a pp collider with a maximum beam energy of 20 TeV and a maximum luminosity of about 10^{33} cm^{-2} sec^{-1}. (Quoting values for the luminosity and certain other accelerator parameters was and still is virtually guaranteed to generate a lively discussion. Arguments about the merits of particular sites and of specific magnet designs were verboten in order to avoid fistfights in the halls.)

The luminosity $\mathcal{L}$, or event rate R per unit cross section σ_{tot}, for two identical round Gaussian bunched beams meeting head-on can be written

$$\mathcal{L} = \frac{R}{\sigma_{tot}} = \frac{N_b^{\,2}}{4\pi\sigma^{*2}\cdot t_b}, \qquad (1)$$

where

N_b = the number of protons per bunch in each beam,

σ^* = the r.m.s. transverse beam size at the interaction point, and

t_b = the time interval between bunches.

Relationships involving the average number of events $\langle n\rangle$ and the luminosity L_b per bunch-bunch encounter follow easily from the above:

$$\langle n\rangle = Rt_b = \mathcal{L}\sigma_{tot}t_b = L_b\sigma_{tot}, \qquad (2)$$

in which

$$L_b = \frac{N_b^{\,2}}{4\pi\sigma^{*2}} = \mathcal{L}t_b. \qquad (3)$$

The normalized transverse emittance ϵ_n and the lattice function β^* determine the beam size via the relationship

$$6\pi\sigma^{*2} = \frac{\epsilon_n\beta^*}{\beta\gamma}, \qquad (4)$$

where γ is the proton energy divided by the proton mass and $\beta = v/c$ is taken equal to one in the following equations. The luminosity can then be rewritten

$$\mathcal{L} = \frac{3\gamma N_b{}^2}{2\beta^* \varepsilon_n t_b}. \tag{5}$$

The beam-beam interaction, in which the electromagnetic fields of each beam tend to disrupt the other, places an important constraint on these parameters. The linear beam-beam tune shift $\Delta\nu_{bb}$ per head-on bunch-bunch encounter, given by

$$\Delta\nu_{bb} = \frac{3r_p N_b}{2\varepsilon_n}, \tag{6}$$

where $r_p = 1.535\times10^{-18}$ meters is the classical electromagnetic radius of the proton, is conventionally used as a measure of the strength of these nonlinear effects. A tune shift of 0.003 is usually regarded as a safe upper limit for hadron colliders; J. Gareyte reported, in his beautiful plenary talk, that tune shifts of 0.003 are tolerable in the SPS collider. This limit can be explicitly taken into account by writing the luminosity in terms of the tune shift

$$\mathcal{L} = \frac{2\gamma(\Delta\nu_{bb})^2\varepsilon_n}{3r_p^2\, \beta^* t_b}. \tag{7}$$

The total number N_{tot} of protons in each ring is related to N_b and t_b by

$$N_{tot} = \frac{2\pi R}{ct_b} N_b, \tag{8}$$

where c is the speed of light and R is the average machine radius. Reducing the total number of particles will help to avoid quenches caused by fractional beam losses and to minimize the damage caused by accidental losses of the whole beam. However, to take an extreme example, with five interaction regions operating at 10^{33}, 10^9 protons in each beam will interact per second; so N_{tot} must be at least of order 10^{14} to achieve a reasonable luminosity lifetime in the face of the desired interactions. The stored energy in a beam of 10^{14} 20-TeV protons is 0.32 gigajoules, about 200 times what the Tevatron has seen so far and enough to lift ten Tevatron dipoles to the top of the Sears Tower! (The beam-abort systems will require a lot of care.) The significant amount of synchrotron radiation, which places an additional load on the refrigeration system and causes problems for the vacuum system, is also proportional to N_{tot}. It is then interesting to write the luminosity in terms of the total number of particles

$$\mathcal{L} = \frac{c\gamma\Delta\nu_{bb}N_{tot}}{2\pi r_p R\beta^*}. \qquad (9)$$

The factor γ/R is proportional to the magnetic field strength.

To achieve a coherent approach to the above relationships, I adopt a viewpoint based on the following premises:

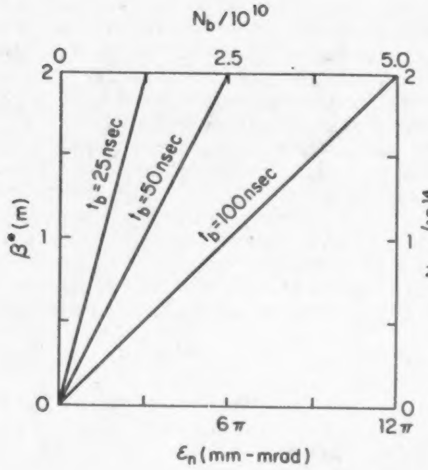
a) The SSC design will depend upon the desired maximum luminosity, even though the collider may usually operate at lower values. It is then reasonable to compare parameter sets resulting in the same maximum luminosity; thus in the following, I hold $\mathcal{L}$ constant at 10^{33} cm^{-2} sec^{-1}. You can easily scale to your own favorite number; I am aware that lower luminosities are easier to achieve and to use!

b) The SSC will operate at the largest attainable $\Delta\nu_{bb}$ when peak luminosity is desired, because for a given luminosity N_{tot} is inversely proportional to $\Delta\nu_{bb}$. This (presently unknown) maximum tolerable $\Delta\nu_{bb}$ will be a characteristic of the machine. So I regard $\Delta\nu_{bb}$ as a constant having the value 0.003. (Again, scaling is easy.)

For constant tune shift, N_b is proportional to ϵ_n. If, in addition, $\mathcal{L}$ is constant then Eq. (9) implies that N_{tot} is proportional to β^*, and Eq. (7) implies that β^* is proportional to ϵ_n/t_b. These relationships are all summarized in the figure at the top of the next page, which was drawn for a ring radius of 20 km, corresponding to dipole strengths like those of the Tevatron. The following paragraphs discuss where to operate on the figure.

The Lattice Function β^*

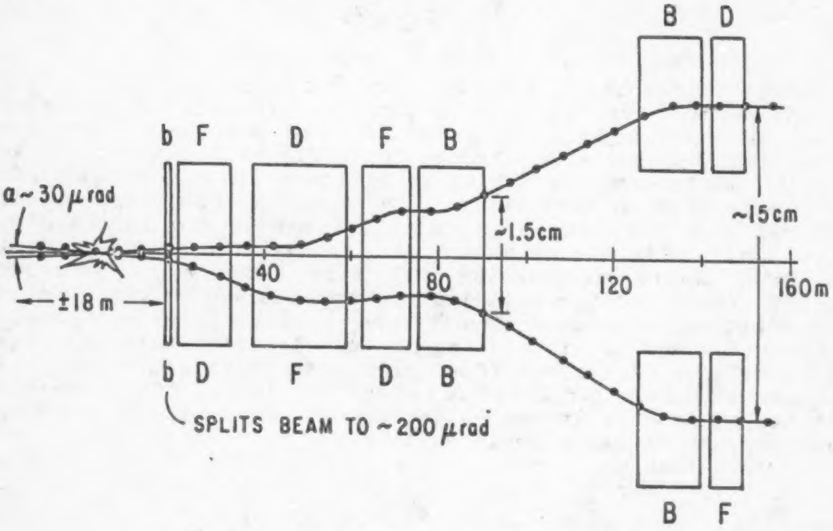
By reducing the lattice function β^*, the luminosity can be increased, or the total number of particles decreased, without affecting the beam-beam tune shift. However, reducing β^* inevitably raises the already high values of β in the low-β quadrupoles, resulting in great sensitivity to field errors and magnet misalignments. Similarly, severe chromatic effects are generated. At Ann Arbor, Tom Collins presented an elegant distribution of sextupoles to correct the chromatic effects. Still, the complicated question of how small a β^* might be achieved is best left to the experts, who generally talk about a range from 1 to 2 meters for the SSC. Eventually, the beam will answer the question!



Minimum beta value as a function of emittance.

The Bunch Spacing

A new small-angle crossing scheme which allows close bunch spacing and hence few interactions per crossing was developed at Ann Arbor. The schematic layout shown below, drawn by Bob Diebold, illustrates the idea. A small crossing angle is used to


B D
b F D F B
α~30μrad
~1.5cm
~15cm
40
80
120
160m
±18m
b D F D B
SPLITS BEAM TO ~200μrad
B F

Sketch of the small-angle region.

separate the beams by several r.m.s. widths at the undesired bunch encounters that occur before the beams are separated by dipoles, reducing beam-beam effects at such "close encounters" to tolerable levels. To maintain the luminosity close to its head-on value while generating the desired separation nearby, the r.m.s. bunch length must be considerably less than β^*, which must in turn be considerably less than the bunch spacing ct_b. These are not severe requirements; short bunches are beneficial for the experimenters anyway, and small β^* is certainly required to achieve high luminosity. This crossing scheme, which will be discussed in detail in the workshop proceedings, allows bunch spacings as small as 5 meters or so (t_b = 16.7 nsec). Only detectors having a significant subset of elements with comparable time resolution would benefit from close bunch spacing.

The Normalized Emittance

High-energy beams in the Fermilab Main Ring, the CERN SPS, and the Brookhaven AGS have normalized emittances greater than about 20π mm-mrad. The graph on the previous page implies that the SSC needs much smaller emittances. It is interesting to review the evolution of emittances through Fermilab's accelerators (as Sho Ohnuma has recently done in EXP-111) and to ask how one might do better. The normalized emittances of our Linac beam are about 4π mm-mrad for 25 mA of H^-beam. Even smaller emittances might be achieved with an RFQ feeding the Linac, but the present emittance is small enough. However, in the Booster, space-charge effects cause the emittance to grow until the space-charge tune shift, approximated by

$$\Delta\nu_{sc} = \frac{3r_pN}{2\epsilon_n\beta\gamma^2B} \tag{10}$$

is reduced to a tolerable value. B, the bunching factor, is the ratio of average current to peak current. The similarity between the above relation and Eq. (6) for the beam-beam tune shift implies that space-charge effects in the first Booster could well limit SSC performance by making it difficult to reach the maximum tolerable beam-beam tune shift. To reduce space-charge effects, the first Booster needs high injection energy (to increase $\beta\gamma^2$) and/or small radius (to reduce the number of particles in the small ring while maintaining the line density in subsequent stages). These requirements imply a small momentum range for the first Booster. Subsequent emittance dilution can be caused by instabilities and by mismatching in beam transfer between stages. In the collider, intrabeam (Coulomb) scattering causes diffusion which is important for emittances smaller than about 5π mm-mrad. In short, great care is needed throughout the accelerator cascade to achieve and maintain small emittances.

The Injection Energy

The choice of injection energy for the 20-TeV rings, studied by the second working group, is influenced mainly by persistent currents in the superconductor, which generate large sextupole and higher moments in the dipoles at low fields. (Presumably superferric magnets would tolerate a lower injection energy whereas small-aperture dipoles would require higher energy.) Shortly before the workshop, the Tevatron beam was easily decelerated to about 65 GeV with the aid of carefully programmed average multipole correction circuits. Perhaps emboldened by this success, people converged on an injection energy of 1 TeV for the SSC. Although this represents a considerabale extrapolation, it also exemplifies how Tevatron experience can guide SSC design efforts, as emphasized by Rol Johnson in his workshop summary of Tevatron results. On a related subject, a small subgroup tried to identify what future machine studies on existing facilities are needed most to resolve uncertainties in the SSC design.

Short Shrift

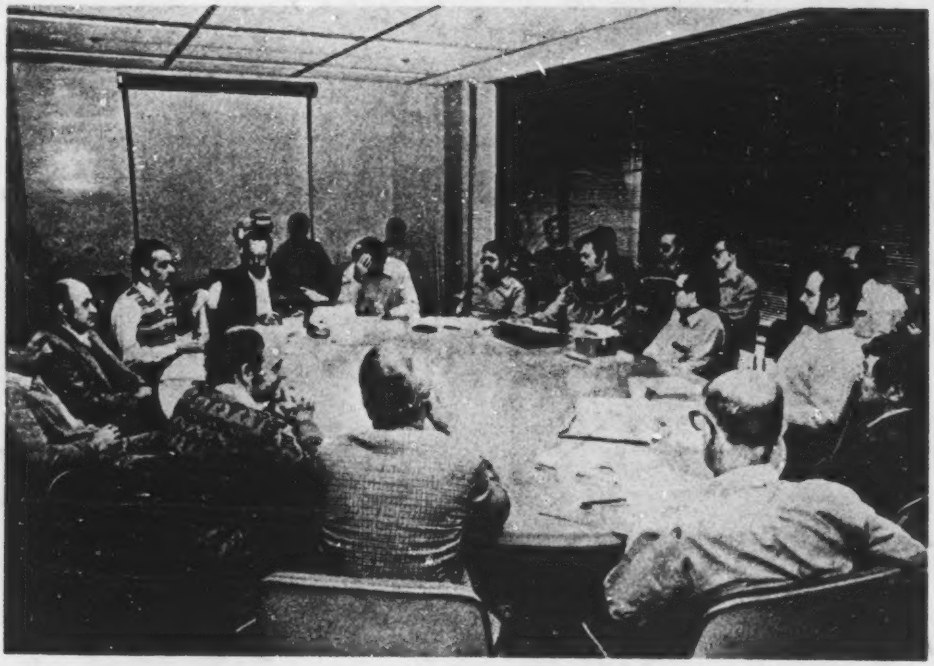
Besides the aforementioned work on correction of chromatic aberrations and on persistent currents, the lattice optics group considered the design of standard cells, surveying errors and orbit correction, insertions for injection and aborting the beam, terrain-following, and "Siberian snakes" to preserve beam polarization.

The stability group looked at single-particle and collective effects. Comparison of Tevatron behavior with predictions based on magnetic measurements has generated confidence in the analytic treatment of single-particle instabilities such as resonances driven by field errors. In contrast, tracking, wherein individual particles are numerically integrated through many turns, is in its infancy; although there is much worldwide activity, realistic simulation of long-term phenomena such as the beam-beam interaction requires enormous computing power. On the collective front, Tom Weiland is developing a three-dimensional program to calculate impedances of structures in the beam environment. Bob Siemann concluded that "we know enough about collective effects to understand their effect on the design of an SSC."

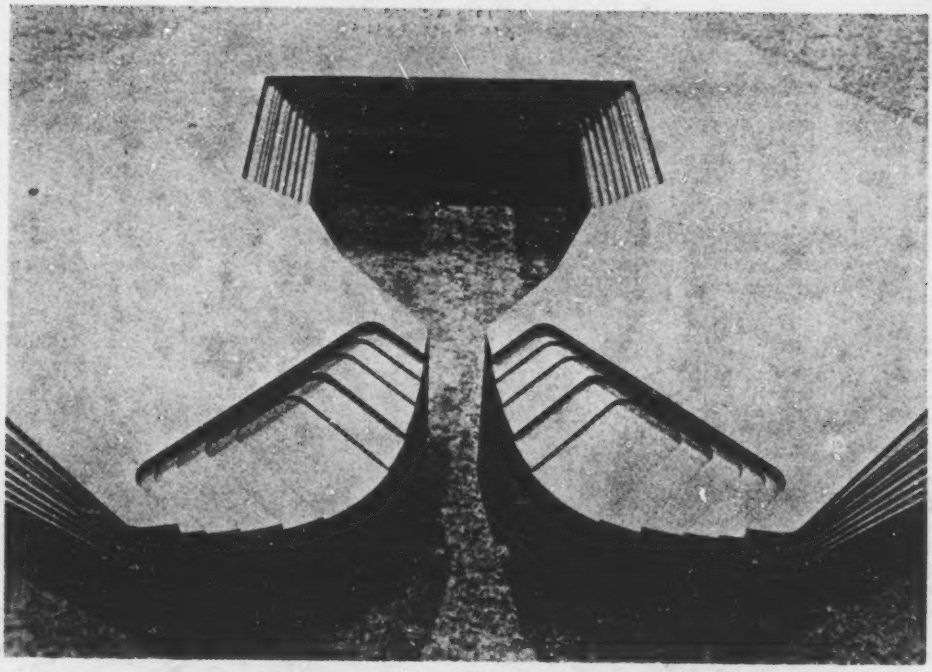
The aperture group studied the effect of magnet aperture on field accuracy, persistent sextupole and higher moments, dynamic aperture, instabilities, vacuum, and costs.

The subsystems group considered requirements on the vacuum and rf systems. Although the vacuum system needs considerable care, present state-of-the-art techniques seem adequate. The interesting idea of using a shiny beam tube to pipe the synchrotron radiation to warm absorbers unfortunately places impractically severe requirements on the surface. The rf requirements are set by the large momentum spread required to control instabilities via Landau damping and by the short bunches desired to facilitate the small-angle crossing scheme and to limit the luminous region for the detectors. The result will be a high-frequency rf system with empty buckets between the bunches.

The beam cooling group, which examined the antiproton-proton alternative, concluded that a three-ring antiproton source would allow luminosities of order 10^{32} cm^{-2} sec^{-1}.



A meeting of the DO Collaboration. Paul Grannis, the head, is at top left in the striped sweater.
(Photograph by Fermilab Photo Unit)



End packs of TeV I quadrupole laminations. The end laminations are glued in a pack to give rigidity to the structure and are shaped to give the desired magnetic-field shape.
(Photograph by Fermilab Photo Unit)

MANUSCRIPTS, NOTES, LECTURES, AND COLLOQUIA PREPARED OR PRESENTED FROM FEBRUARY 20, 1984 TO MARCH 9, 1984

Copies of preprints with Fermilab publication numbers can be obtained from the Publications Office or Theoretical Physics Department, 3rd floor east, Central Laboratory. Copies of some articles listed are on the reference shelf in the Fermilab Library.

Experimental Physics

G. N. Taylor et al. Experiment #388	Limits on the Neutrino Oscillations $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$ Using a Narrow-Band Beam (Phys. Rev. D28, 2705 (1983)

Theoretical Physics

C. T. Hill and D. N. Schramm	The Ultra-High Energy Cosmic Ray Spectrum (FERMILAB-Pub-83/89-THY; submitted to Phys. Rev. D)
S.T. Petcov	Possible Signature for Production of Majorana Particles in e^+-e^- and p-$\bar{p}$ Collisions (FERMILAB-Pub-84/26-T; submitted to Phys. Lett. B)
J. D. Bjorken	Coupled Bunch Instabilities in a $p\bar{p}$ Collider (FERMILAB-Conf-84/29-T; contributed to the Workshop on $\bar{p}p$ Options for the Super Collider, University of Chicago, February 12-17, 1984)

General

A. E. Brenner	The Future of Computing Technology in Physics - The Potentials and Pitfalls (FERMILAB-Conf-84/27; invited talk given at the 1984 Annual Joint APS/AAPT Meeting, San Antonio, Texas, February 2, 1984)
K. Y. Ng	An Estimate of the Longitudinal and Transverse Impedances for the Superconducting Super Collider (Submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)

R. E. Shafer	On the Coupling Impedance of Position Monitor Electrodes (Submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)
P. Limon	The Pressure Bump Instability in Very Large Cold Bore Storage Rings (Submitted to the Workshop on Accelerator Physics Issues for a Superconducting Super Collider, Ann Arbor, Michigan, December 12-17, 1983)

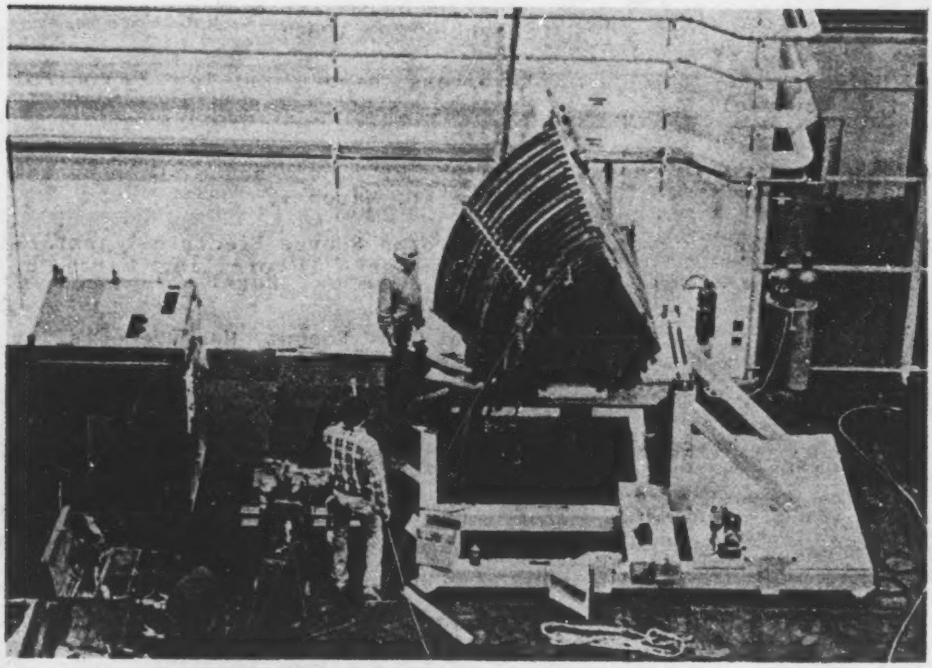
Physics Notes

L. Michelotti	Moser-Like Transformations Using the Lie Transform (FN-397)
M. Harrison and F. N. Rad	Symmetric and Non-Symmetric Lambertson Magnets (FN-398; submitted to Nucl. Instrum. Methods)

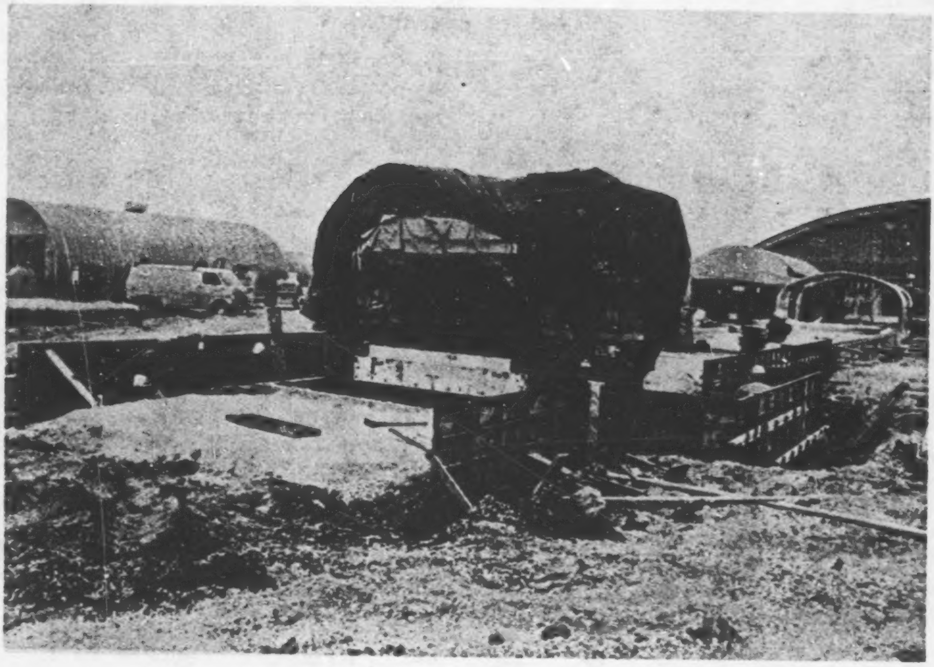
Colloquia, Lectures, and Seminars

L. McLerran	"Quark Plasma" (Fermilab, February 20/22 1984)
C. Rode and J. Carson	"Report on the SSC Magnet Workshop at LBL, February 13-16, 1984" (Fermilab, February 21, 1984)
M. Kuchnir	"SQUID Based Beam Current Meter Prototype" (Fermilab, February 23, 1984)
P. Rapidis	"Techniques of Measuring Current in the Accumulator" (Fermilab, February 23, 1984)
D. Anderson	"Some New Ideas in Detectors" (Fermilab, February 23, 1984)
J. Schonfeld	"What You Should Know (Things Your Mother Never Told You) about Colliding-Beam Storage Rings" (Fermilab, February 24, 1984)
J. Schonfeld	"Colliding Beam Instabilities" (Fermilab, February 27/29, March 5/7, 1984)

S. Das	"The Uses of Large N" (Fermilab, February 28, 1984)
E. Malamud and D. McConnell	"Progress Report on Tev I Control System Design" (Fermilab, March 1, 1984)
G. Lee	"Status of the Vacuum Components" (Fermilab, March 1, 1984)
R. Oberholtzer	"Antiproton Source Electrical Installation Plan" (Fermilab, March 8, 1984)
S. Mtingwa	"Report on Recent Measurements at Argonne" (Fermilab, March 8, 1984)



Assembly of a module of the Collider Detector.
(Photograph by Fermilab Photo Unit)



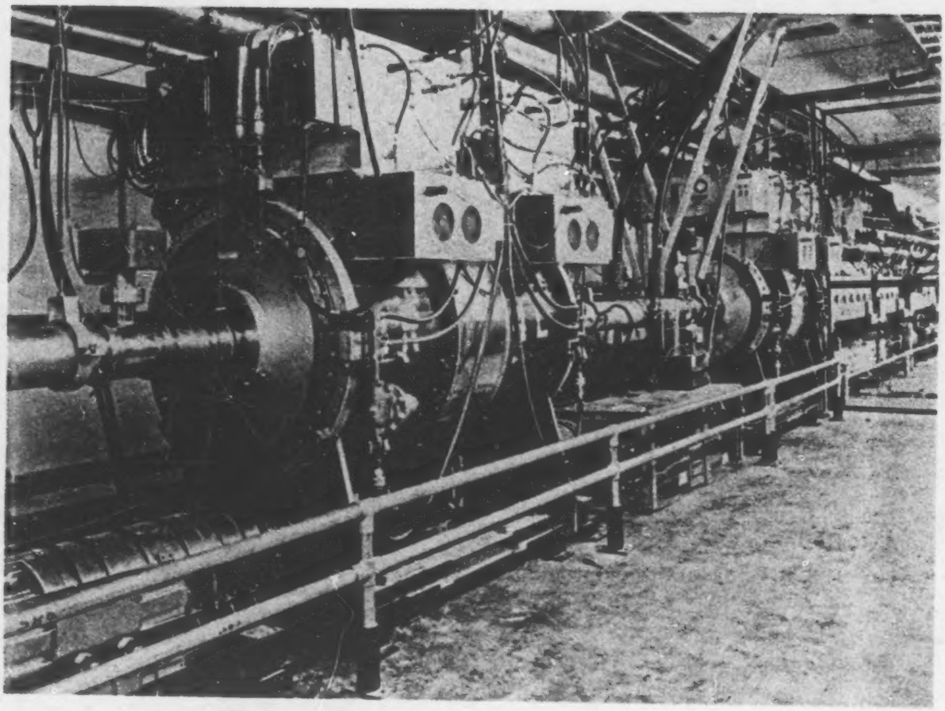
Construction work in M Center in the Meson Area.
(Photograph by Fermilab Photo Unit)

DATES TO REMEMBER

April 19-20, 1984	PAC Proposal Presentation Meeting
April 27-28, 1984	Annual Users Meeting
April 28, 1984	Energy Saver Dedication Ceremony
May 2-4, 1984	"Inner Space-Outer Space," Workshop on High-Energy Physics, Astrophysics, and Cosmology, Fermilab
May 23-30, 1984	Conference on the Intersections Between Particle and Nuclear Physics, Steamboat Springs, Colorado, May 23-30, 1984 (for more information contact Marion Heimerle, Brookhaven National Laboratory)
June 16-22, 1984	Extended Summer Meeting of the Physics Advisory Committee
August 13-24, 1984	U. S. Summer School on Particle Accelerators, Fermilab

fermilab report

Fermi National Accelerator Laboratory Monthly Report April 1984



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F. T. Cole, R. Donaldson, and L. Voyvodic, Editors

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Contributions, comments, and requests for copies should be addressed to the Publications Office.

FERMILAB-84/4 Fermi National Accelerator Laboratory 0090.01

THE COVER: Beam-coalescing cavities installed in the Main Ring for Tevatron I; an Energy-Saver cavity is beneath.
(Photograph by Fermilab Photo Unit)

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

SIGMA MINUS BETA DECAY - Experiment 715

Peter S. Cooper
Yale University

E. Swallow, Elmhurst College; J. P. Berge, A. Brenner, P. Grafstrom, E. Jastrzembski, J. Lach, J. Marriner, R. Raja, Fermilab; E. W. Anderson, Iowa State University; A. Denisov, V. Grachev, A. Kulikov, V. Schegelsky, D. Seliverstov, N. Smirnov, N. Terentyev, I. Tkach, A. A. Vorobyov, Leningrad Institute of Nuclear Physics; S. Y. Hsueh, D. Müller, J. Tang, R. Winston, G. Zapalac, University of Chicago; E. McCliment, University of Iowa; C. Newsom, P. Razis, L. J. Teig, Yale University

Introduction

Experiment 715 marks both the beginning and the end of an era. It is the last approved experiment of the Fermilab 400-GeV program and the first experiment to complete data taking with the superconducting Energy Saver. The physics goals are to conclusively measure the sign and magnitude of the form factor ratio (g_A/g_V) in the beta decay of the sigma minus hyperon decaying to neutron, electron, and neutrino ($\Sigma^- \rightarrow ne^-\nu$). This measurement requires the observation of about 10^5 beta decays of polarized sigma minus hyperons.

In this article I will describe some of our experiment and try to give some flavor of what running with the Tevatron may be like, based upon the experiences of our just completed run.

Our experience in using the new accelerator has been an education in several respects. All relevant time scales, from the micro-duty factor of the beam to the schedule of the run, are different enough to significantly change the character of doing physics with the new machine. With a duty factor approaching 40% (15 sec flat top with 39 sec rep rate) data came in at a frightening rate. On the other hand, 50 hours of beam was a good week. Extrapolating this trend leads to planning one-pulse experiments at the SSC.

Physics

In 1981 the last of a series of sigma minus beta decay experiments reported results confirming all previous measurements. The world data at that time consisted of 400 polarized decays in four different experiments plus several thousand unpolarized decays. Their goal was to measure the form factor ratio g_A/g_V in the decay. The unpolarized measurements could measure the magnitude of this ratio from the angular correlation of the electron and neutron. The polarized experiments measured both the magnitude and sign from the angular correlation of the electron momentum and the sigma polarization. The four polarized measurements agree beautifully with one of the two possible solutions allowed by unpolarized experiments. All was in perfect agreement save for the "minor" problem that the Cabibbo model predicted the solution with the other sign! If this sign error could be confirmed the theoretical implications range between "panic and hysteria" in the words of one theorist. Either the Cabibbo model, which works almost perfectly in all other weak decays, is just wrong, or the weak current in sigma minus beta decay is V+A (right-handed), or some even more horrible conclusion must be drawn.

Our experiment grew out of several previous measurements beginning with the discovery of inclusive hyperon polarization by E-8 at Fermilab in 1976. In 1981 we had just concluded E-497 in the charged hyperon beam we had built in Proton Center. In that experiment we had measured the production polarization of sigma minus to be 20%. The hyperon fluxes in our beam are quite large, 5000 sigma minus decays per second in our decay region. The beta decay branching ratio is 1×10^{-3} so we had 5 sigma beta decays per second with 20% polarization. In addition to having three orders of magnitude higher rate than the previous experiments, we could reverse the polarization of the hyperons by reversing the production angle of the sigmas. The previous experiments produced their polarized sigmas from the decay of a low-energy resonance giving them a fixed relationship between the sigma kinematics and its polarization. We had the rate and control of systematic errors to hopefully put this question to rest one way or the other.

Apparatus

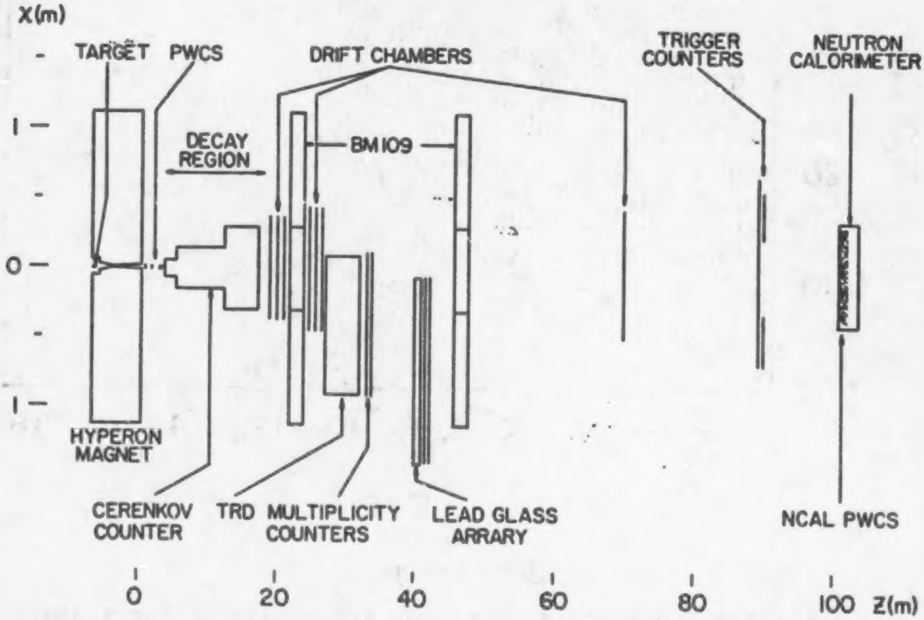
The group which formed for this experiment included the E-497 charged-hyperon group (Fermilab, Iowa, Iowa State, and Yale) together with some of the members of the 1981 sigma beta decay experiment (Chicago and Elmhurst College) and a large group from the Leningrad Institute of Nuclear Physics.

The experiment has two crucial parts. First, we had to find the beta decays and make a clean trigger. For every beta decay $\Sigma^- \to ne^-\nu$ there are 1000 hadronic decays; $\Sigma^- \to n\pi^-$. Second, we must measure the left-right, up-down, and front-back asymmetries in the beta decays to analyze the three polarization components in order to extract the spin-momentum correlation parameter (α_e). Any asymmetry in our apparatus will appear as a false asymmetry which, if uncorrected, systematically biases the measurement of α_e.

The beta decay has two neutral particles in the final state, and the only difference between it and the hadronic decay was in telling an electron from a pion. In order to have a clean sample of beta decays, we need 10000 π/e separation in the 10-100 GeV/c range. Furthermore, any trigger inefficiency leads to a potential asymmetry in our acceptance which will appear as a bias in the data.

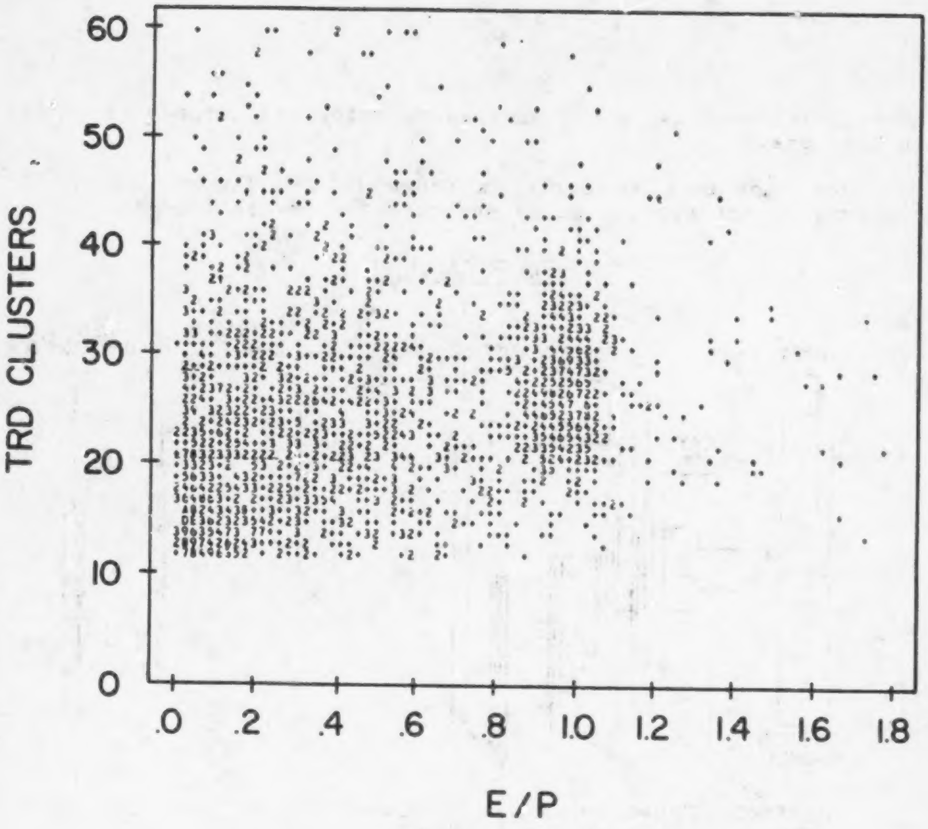
The apparatus we built is shown in the figure below. It consists of the hyperon decay spectrometer we had used in E-497

E-715 PLAN VIEW


X(m)
TARGET
PWCS
DRIFT CHAMBERS
TRIGGER COUNTERS
NEUTRON CALORIMETER
1
DECAY REGION
BM109
0
1
HYPERON MAGNET
CERENKOV COUNTER
TRD
MULTIPLICITY COUNTERS
LEAD GLASS ARRARY
NCAL PWCS
0
20
40
60
80
100
Z(m)

and all the electron identification we could muster. The electron identification relied upon two independent detectors, the transition radiation detector (TRD) and the lead glass array. Each of these alone could give the required π/e separation. Together, they allow us to achieve better than 95% electron efficiency so that our biases are under control.

The TRD was exceptional in this application. It was built completely by our Soviet colleagues and exceeded design performance. It operated as the main trigger element giving 50/1 π/e separation with 99% electron efficiency. The figure at the top of the next page shows a scatter plot of all TRD triggers plotting the number of clusters in the TRD versus the ratio of lead glass energy to magnetically measured momentum. This is an online plot with no significant cuts or serious calibrations done for any of the measurements. The beta decay events are well separated with about 10% background from the hadronic decays.



Data Taking

E-715 was approved in June 1982 and scheduled for a three-month run during the last available 400-GeV running period, the shake-down run of the Energy Saver. It was important that we run this experiment at 400 GeV since the physics of inclusive hyperon production polarization is not understood. It is possible that the 20% sigma polarization we measured at 400 GeV could go to zero at higher energy. The Laboratory was apt to be less than enthusiastic about a request for further 400-GeV running. Therefore, the success of E-715 was clearly tied to our ability to get it done right in the first run and the Laboratory's ability to make the new machine work well enough to do physics.

The run was scheduled for October through December 1983, 15 months after the approval. By the summer of 1983 we were busily installing detectors while the schedule gave no signs of slipping. Indeed, by October the experiment was installed and the beam actually arrived. The plan for the run was one month to reestablish the old experiment, one month to develop the beta decay triggers, and finally, one month to take the data. October appeared to be a disaster. By the end of the month we had received the most beam of any of the five running experiments--27 hours. There was never anything major wrong; the fear of cryogenic magnet failures requiring a week each to fix never materialized. Nonetheless, it appeared that the product of all the probabilities for getting beam to Proton Center was vanishingly small. Although the new machine tended to overshadow it, the whole rest of the Laboratory had been rebuilt during the long shutdown. The switchyard and beam lines were essentially new systems, as was the reorganized Experimental Areas Department. Operation of all three experimental areas was centralized in a single operations center with a completely new beam line controls system. By the end of October a clear design fault became evident; no one had thought to design a crew chief capable of handling by telephone four simultaneously enraged experimenters.

The problems of October proved to be largely learning curve difficulties. By November the machine began to run in earnest producing 30 to 60 hours per week of beam, most of it useable. The schedule was extended until January 20, 1984. In this light, October was a blessing. We had just enough beam to check that the detectors could see the beam and enough access time to fix the things which did not work. From November the run proceeded mainly as we had planned. The machine averaged 50 hours per week of beam. With the spill stretched to 15 seconds with a 39 second repetition rate this amounted to twice as many events per week as we would have had with the old Main Ring. Of course, we were a trigger rate limited experiment. A proton limited experiment would have experienced one-sixth the yield per week.

Beam

The longer spill made checkout seem quite different than in the "old days." Fifteen seconds is not only long enough to make a scope trigger but also to make a measurement. The 24 seconds between spills is almost long enough to get a cup of coffee! Tuning a beam line at one point every 39 seconds can be painful, but our beam line was so simple that we had very little tuning to do.

The spill structure of a 15-second beam can be amazing. We ran for the first month with our beam flickering on and off at 60 hertz due to switchyard power supplies not regulating. Since everything was designed for 800 GeV some supplies were required to put out almost zero current in order to transport 400-GeV beam. Beam oscillations were observed at 4.5 hertz, 20 hertz, 60 hertz, and all its harmonics and other assorted frequencies. Some of these frequency components were understood; the 20 hertz went away when the mechanical vacuum pumps were removed from the Saver magnets. Other frequency components seemed to come and go as they pleased. There is clearly much yet to be learned about the subtleties of the superconducting ring.

The most sobering effect of the long spill is to stand in front of the tape drive while taking data. The beam arrives and the tape begins to spin at maximum speed. It continues to spin for what seems like forever! At 6250 bpi one has visions of drowning in data from a rather brief run. E-715 is a modest spectrometer by today's standards with 350 16-bit words per event. At 1500 events per spill with 50% deadtime we wrote 450 tapes in 300 hours of data taking.

Results

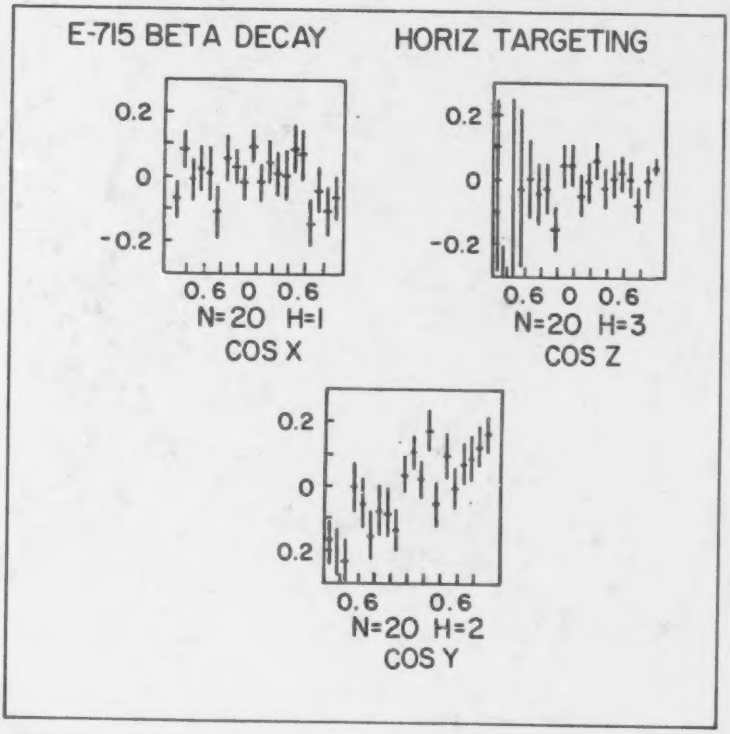
Six weeks after the completion of a first run is clearly too soon to be quoting results of an experiment. Nonetheless, we can give some characterization of our data here based completely upon an on-line analysis which we carried out during the data taking. We had resolved that since E-715 was to be a one-run experiment we would have to be able to analyze the data as we took it. The shortcoming of such an approach is that there is no time to do any of the detailed studies or calibrations that a real analysis requires.

The plots in the figure on the next page are angular distributions of the electron in the sigma center of mass plotted versus the electron momemtum's direction cosines. The quantity actually plotted is $\alpha_e P_\Sigma \cos\theta_e$ and is calculated from spin up and down data in such a way as to cancel the acceptance of the detector. The slope of the data is proportional to α_e times the sigma polarization component in that direction. The data plotted are 4800 beta decays with the sigma polarization in the vertical (Y) direction, half up and half down. There appears to be a significant slope in the Y direction as expected and zero slope in the other two directions. The sign of the Y slope is a direct test of the Cabibbo model prediction. With much work and considerable luck the results of our off-line analysis will look this good.

Our total data sample contains about 88000 beta decays including data taken with the sigma polarization vertical as above, and also in the horizontal plane. One fifth of the events are taken with zero polarization as a systematic check.

We have begun the analysis of these data and hope to be able to report preliminary results for α_e in the near future.

I have not discussed in this report the tracking neutron calorimeter which will allow us to completely reconstruct the sigma beta decays and measure the spin-momentum correlation parameters of the neutron and neutrino as well as the electron. The hardware for these measurements seem to have worked quite well. We have less quantitative understanding of these measurements at this time, but we are optimistic that they will produce

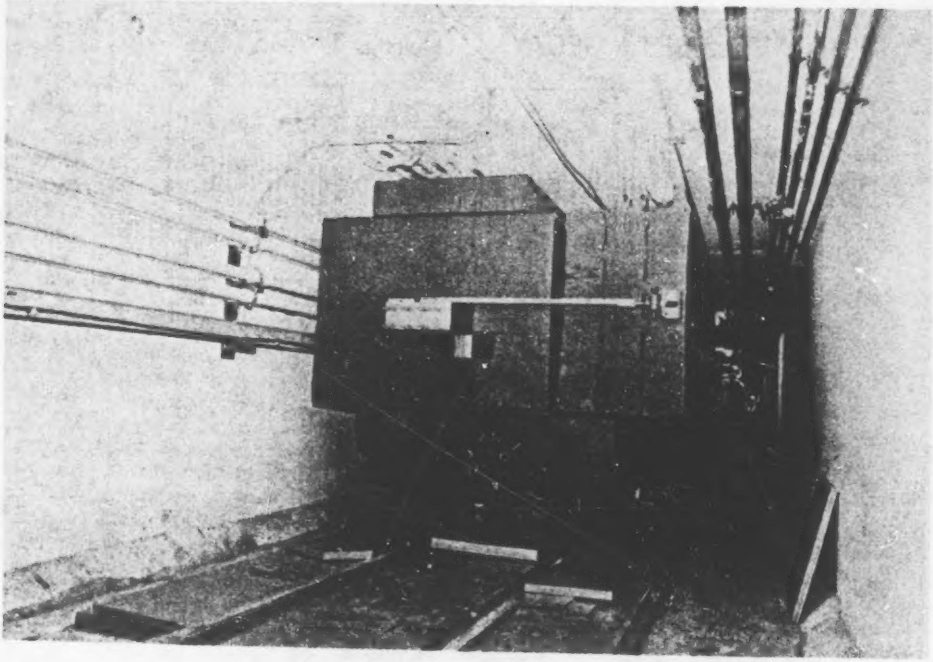


independent measures of the form factor ratio in addition to the α_e analysis.

Conclusions

The superconducting accelerator seems to be a place where it is possible to do physics in a timely way, albeit in a manner somewhat different than in the past. The Fermilab schedule held firm over the whole life of E-715 in spite of considerable uncertainties during the installation of the new machine. If this past running period is a good example, the reliability of the Fermilab schedule will be an asset in the planning of future experiments.

Extrapolating our recent experiences and assuming no serious problems develop in running the machine at 800 GeV, one can envision the Tevatron opening a new range of fixed-target physics with both higher energy and greater livetimes. We received one week in January with 100 hours of beam. The prospect of reliable 800-GeV beam with four times the livetime of the 400-GeV machine certainly leads us to think of new experiments these developments make possible.



Neutrino Center dump
(Photograph by Fermilab Photo Unit)

DEDICATION PROGRAM
FERMILAB AUDITORIUM
APRIL 28, 1984

PRELUDE:	*"Abstract"* and *"Proposal"*	Music synthesis by Walter Kissel
CHAIR:	H. Guyford Stever	President, Universities Research Association, Inc.
SPEAKERS:	Leon M. Lederman	Director, Fermi National Accelerator Laboratory
	Charles H. Percy	Senior Senator, Illinois
	James R. Thompson	Governor, State of Illinois
	John T. Myers	Congressman, Indiana, Ranking Minority Member Subcommittee on Energy and Water Development
	George A. Keyworth	Science Advisor to the President and Director, Office of Science & Technology Policy
Address:	Danny J. Boggs	Deputy Secretary of Energy

Videotape: "Construction of the Energy Saver"
Background Music: *"Continuity"* Music synthesis

The dedication program may be viewed in the atrium on large screen.

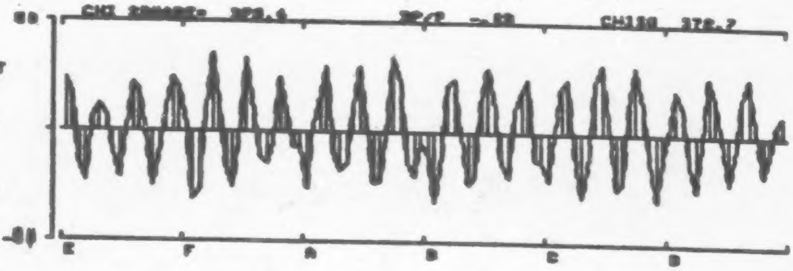
ENERGY SAVER NEWS

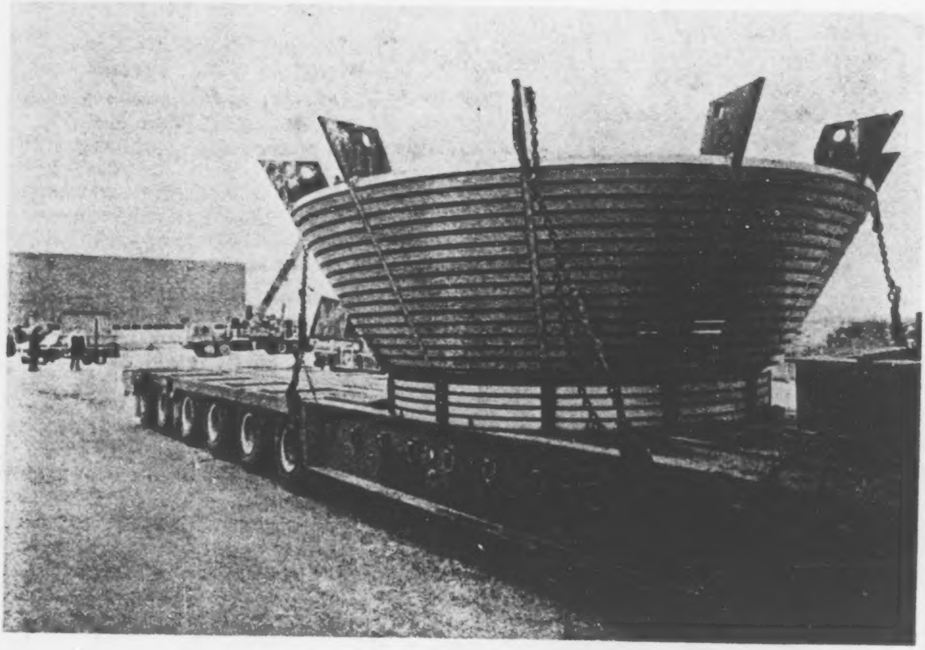
Stanley Pruss

The 400-GeV HEP program officially ended at 0600 on February 14. This completed the Energy Saver program and started the Tevatron Era. During the next two days, the Tevatron was ramped to 825 GeV and was run at dc for 20 minutes at 800 GeV in storage mode. Beam was accelerated to 800 GeV and extracted. During the three-week shutdown that followed, the quadrupoles and other equipment necessary for low β at B0 were installed.

During the Tevatron cooldown, over the period March 10 to March 14, the Main Ring was started up. The only major problem was a Main-Ring quadrupole near B0 that had been misaligned by 1.000 in. during low-β installation. This was found by its rather remarkable effect on the 150-GeV Main-Ring closed orbit as can be seen in the accompanying logbook page. The first attempt to ramp the Tevatron on March 15 resulted in a quench near B0 at 270 GeV. This was eventually traced to an unsoldered splice in the superconducting cable. In the remarkably short time of 3 days, the area of the bad splice was warmed, the cryostat and the liquid helium pipe opened, the splice repaired and everything put back together and cooled down. By March 19, we had low-intensity 800-GeV beam. During the following week, much retuning of the Tevatron was done to reduce injection and acceleration losses so as to increase the intensity. By March 25, the Tevatron was delivering 800-GeV beam to all three experimental areas and HEP was declared to have started. The next day, a ground fault occurred in the Tevatron. This fault only occurred at 600 GeV or higher and thus appeared due to conductor motion at high field. This repair took five days because the exact location of conductor motion could not be established, and, therefore, three dipoles were replaced. By April 1, HEP was once again declared. The following two weeks saw a host of minor problems interrupted frequently by HEP. Machine studies during this period began on a host of improvements for future use. These include the powering of the low-β quads, first fast (1 msec) extraction at 800 GeV and establishment of the Monday, Thursday, and Friday shifts as standard parasitic study periods. In spite of all of these distractions, HEP is getting more real beam time every week and work is beginning on many of the improvements needed for Tevatron I.

700 Beam accelerated to end of flattop. The resulting closed orbit tells the story. An orbit distortion introduced in the vicinity of B11 has make the C.O. terrible, and of course E44 was near the peak of the oscillation. Therefore a large negative Ref bump was needed to get beam all the way out.





The end plug of the Collider Detector.
(Photograph by Fermilab Photo Unit)

FERMILAB ANNUAL USERS MEETING
RAMSEY AUDITORIUM, APRIL 27-28, 1984

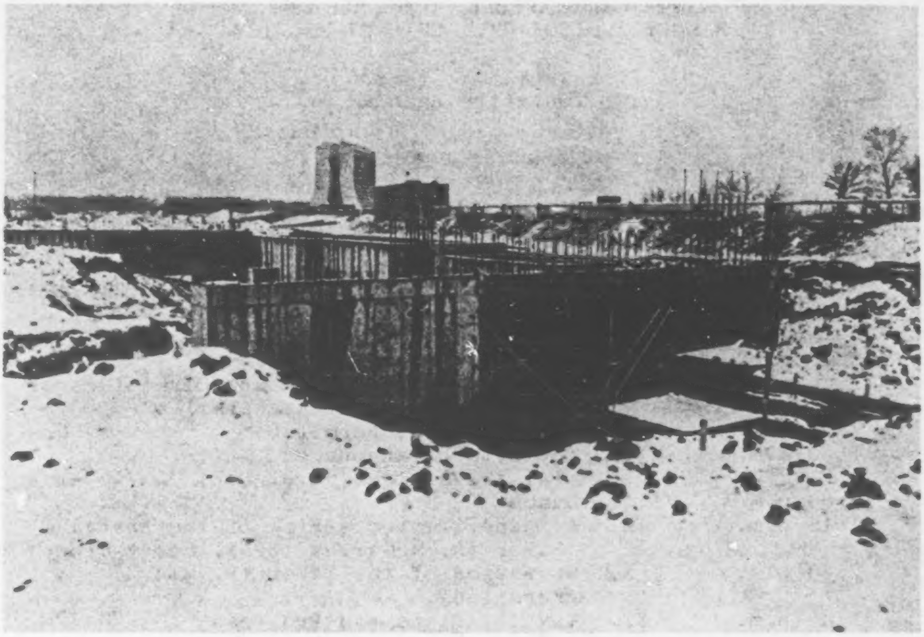
Tentative Agenda

Friday, April 27

8:30 a.m.	I.	Registration
9:30 a.m.	II.	Users Executive Committee Report (S. Loken, LBL)
9:45 a.m.	III.	URA Report (G. Stever, URA)
10:00 a.m.	IV.	The State of the Laboratory (L. Lederman, Fermilab)
10:45 a.m.	V.	Coffee Break
11:10 a.m.	VI.	"Status Report and Future Directions of Central Computing at Fermilab" (A. Brenner, Fermilab)
11:30 a.m.	VII.	Topic to be announced (A. Trivelpiece, U.S. DOE)
12:00 p.m.	VIII.	Lunch
1:15 p.m.	IX.	An Experimenter's View of the Energy Saver (R. McCarthy, SUNY, Stony Brook)
1:30 p.m.	X.	Operation of the Saver (R. Mau, Fermilab)
1:45 p.m.	XI.	TeV II, Plans and Progress (T. Kirk, Fermilab)
2:15 p.m.	XII.	Experimental Areas Report (R. Dixon, Fermilab)
2:45 p.m.	XIII.	Experimental Schedule (T. Yamanouchi, Fermilab)
3:00 p.m.	XIV.	Discussion and Questions
3:30 p.m.	XV.	Coffee Break
4:00 p.m.	XVI.	Topics to be announced (G. Keyworth, Presidential Science Advisor)
5:00 p.m.	XVII.	Discussion
6:00 p.m.	XVIII.	Social Hour, hosted by Universities Research Association

Saturday, April 28

9:30 a.m.	I.	Commissioning of the Energy Saver (R. Orr, Fermilab)
10:00 a.m.	II.	TeV I Project Report (J. Peoples, Fermilab)
10:20 a.m.	III.	TeV I Experiments (P. Grannis, SUNY, Stony Brook)
10:40 a.m.	IV.	The Next Three Years (J. Bjorken, Fermilab)



Progress on the Tev I Target Hall.
(Photograph by Fermilab Photo Unit)

MANUSCRIPTS, NOTES, LECTURES, AND COLLOQUIA PREPARED OR PRESENTED FROM MARCH 10, 1984 TO APRIL 15, 1984

Copies of preprints with Fermilab publication numbers can be obtained from the Publications Office or Theoretical Physics Department, 3rd floor east, Central Laboratory. Copies of some articles listed are on the reference shelf in the Fermilab Library.

Experimental Physics

P. Callahan et al. Experiment #401	Photoproduction from 45 to 225 GeV (FERMILAB-Pub-84/36-E; submitted to Phys. Rev. Lett.)
M. D. Sokoloff Experiment #546	Evidence for Hard Gluon Bremsstrahlung in a Neutrino Experiment (Ph.D. Thesis, University of California, Berkeley, May 1983)

Theoretical Physics

S. R. Das and J. B. Kogut	A Study of the Hot Twisted Eguchi-Kawai Model (FERMILAB-Pub-84/14-T; submitted to Phys. Lett. B)
M. Gronau et al.	Extending Limits on Neutral Heavy Leptons (FERMILAB-Pub-84/24-T; submitted to Phys. Rev. D)
A. Sen	Role of Conservation Laws in the Callan-Rubakov Process with Arbitrary Number of Generation of Fermions (FERMILAB-Pub-84/28-T; submitted to Phys. Rev. Lett.)
Y. Munehisa	First-Order Phase Transitions in a U(1) Lattice Gauge-Higgs Theory (FERMILAB-Pub-84/31-T; submitted to Phys. Rev. D)

Astrophysics

E. W. Kolb and M. S. Turner	Limits from the Soft X-Ray Background on the Temperature of Old Neutron Stars and on the Flux of Superheavy Magnetic Monopoles (FERMILAB-Pub-84/30-A; submitted to the Astro-Physics Journal)

M. S. Turner et al.	The "Flatness of the Universe": Reconciling Theoretical Prejudices with Observational Data (FERMILAB-Pub-84/32-A; submitted to Phys. Rev. Lett.)

General

A. D. McInturff	Superconducting Metals and Alloys Help Further "Science of the Impossible" (Research & Development, March 1984)
A. D. McInturff et al.	Measurement of Critical Temperature as a Function of Field [Cryogenics 24, 214 (1984)]

Colloquia, Lectures, and Seminars

D. Lindley	"Basic Cosmology" (Fermilab, March 12, 1984)
R. Orr	Accelerator Division Information Meeting (Fermilab, March 13, April 3, 1984)
D. Lindley	"Basic Cosmology" (Fermilab, March 14, 19, 21, 1984)
R. Pasquinelli	"Current Design Status of the Low Level Preamps and Medium Level System for 1-2 GHz and 2-4 GHz" (Fermilab, March 15, 1984)
M. S. Turner	"Big Bang Cosmology: From Quark Soup to the Expanding Universe" (Fermilab, March 16, 1984)
G. Coutrakan	"Ring Imaging Cerenkov Results Using Multi-Needle Detectors" (Fermilab, March 22, 1984)
P. Grannis	"Calorimetry" (Fermilab, March 26, 28, 1984)
C. Rode	"The Fermilab 5T SSC Design" (Fermilab, March 27, 1984)
S. Ohnuma	"Field Quality of Magnets and the Storage Capability of our Rings" (Fermilab, March 29, 1984)

B. Brown	"Status Report on Magnet Production and Measurement" (Fermilab, March 29, 1984)
M. Atac	"Breakdowns, Sparks, Rates and Long Lifetimes" (Fermilab, March 29, 1984)
M. Palmer	"Proton Beam Dump for the $\overline{p}$ Target Station" (Fermilab, April 5, 1984)
C. Hojvat	"Plans for $\overline{p}$ Yield Measurements and Related Instrumentation" (Fermilab, April 5, 1984)
C. Bunker	"Invitation to Users for Testing Production Programs on the CYBER 875 Under NOS 2" (Fermilab, April 9, 1984)
A. Ruggiero	"BNL Relativistic Heavy Ion Collider Project - RHIC" (Fermilab, April 10, 1984)
K. Koepke	"Performance of the Low Beta Insertion at B0" (Fermilab, April 12, 1984)
J. Griffin	"Status of Bunch Coalescing with Digressions" (Fermilab, April 12, 1984)

DATES TO REMEMBER

April 27-28, 1984	Annual Users Meeting
April 28, 1984	Energy Saver Dedication Ceremony
May 2-4, 1984	"Inner Space-Outer Space," Workshop on High-Energy Physics, Astrophysics, and Cosmology, Fermilab
May 23-30, 1984	Conference on the Intersections Between Particle and Nuclear Physics, Steamboat Springs, Colorado, May 23-30, 1984 (for more information contact Marion Heimerle, Brookhaven National Laboratory)
May 24-25, 1984	Fermilab Industrial Affiliates Annual Meeting
June 16-22, 1984	Extended Summer Meeting of the Physics Advisory Committee
June 23-July 13, 1984	1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, Snowmass, Colorado
August 13-24, 1984	U. S. Summer School on Particle Accelerators, Fermilab

2.1 Fixed-Target Program

1. **What new science is being explored by this program? What scientific opportunities are being exploited?**

   Answer: The major thrust of this research is to understand the properties and behavior of the quark and gluon constituents of nuclear matter and of the nucleon itself. The belief that quarks and gluons exist and are fundamental constituents of nuclear matter is the result of many years of experimentation at lower energy accelerators, and the synthesis by theoretical physicists of that information. Since, however, it has not been possible to liberate quarks or gluons from subnuclear particles, their properties can only be studied by doing experiments which study violent collisions at very high energies in which quark or gluon constituents within the colliding particles interact or in which produced quarks and gluons manifest their presence indirectly, e.g., through jets of particles. It is a very diverse program, since different aspects of basic nucleon structure can be explored in processes proceeding via strong, electromagnetic, and weak nuclear forces. This is accomplished by using a wide variety of different types of particle beams, which interact with the quarks in different but complementary ways. For example, neutrinos are only affected by the weak nuclear force, muons and photons are primarily influenced by electromagnetic forces, and the hadrons interact dominantly through the strong nuclear force. Different types of hadrons; pions, kaons, protons, neutrons and their antiparticles; each contain a different combination of fundamental quarks as their constituents. So experiments using these varieties of beam particles explore differences in how the various quarks interact with one another and with the gluons which appear to hold the quarks together to form the particles. By comparing and collating the results of different studies of this kind, it is possible to derive many of the properties of the different quarks and to understand how they are distributed inside nuclear matter. The ultimate goal of this program of research is to reveal why the quarks combine as they do to form different types of particles, and thereby be able to explain why nuclear and subnuclear matter behave as they do.

   The primary scientific opportunities which are exploited by the fixed-target research program result from the fact that when particles are made to collide at very high reaction energies, much of that energy is converted during the collision into new kinds of matter as described by Einstein's now famous formula, $E=mc^2$. Thus, new forms of subnuclear particles are literally created in these collisions, and the more massive these are the higher is the reaction energy required to create them.

   Other fundamental scientific opportunities also being exploited by the Fermilab fixed-target research program as it moves into new physical domains with the 800-1000 GeV beam energy now available include: the possible massiveness of neutrinos; searches for new types of particles which certain theories have predicted; studies of the detailed properties and characteristics of charmed and strange particles; and careful measurements of those properties of known elementary particles which have not yet been established by experimentation, yet whose values are firmly predicted on the basis of current knowledge.

2. **What types of research instrumentation/experimental devices are available for this program, and what are their capabilities?**

Answer: Major experimental facilities available for fixed-target research by qualified user groups include: the fifteen foot cryogenic bubble chamber; a multi-particle spectrometer; two several thousand ton neutrino detectors; a very large superconducting spectrometer magnet; and a massive conventional magnet spectrometer capable of accepting very intense beams. Several other special purpose experimental devices are also available or are now being fabricated. Each of the fifteen secondary beam lines used for the fixed-target program will be equipped for research soon after the time the Tevatron II project reaches completion at the end of FY 1985. The attached excerpt from a Fermilab report provides a brief description and plan layout for each approved fixed target experiment.

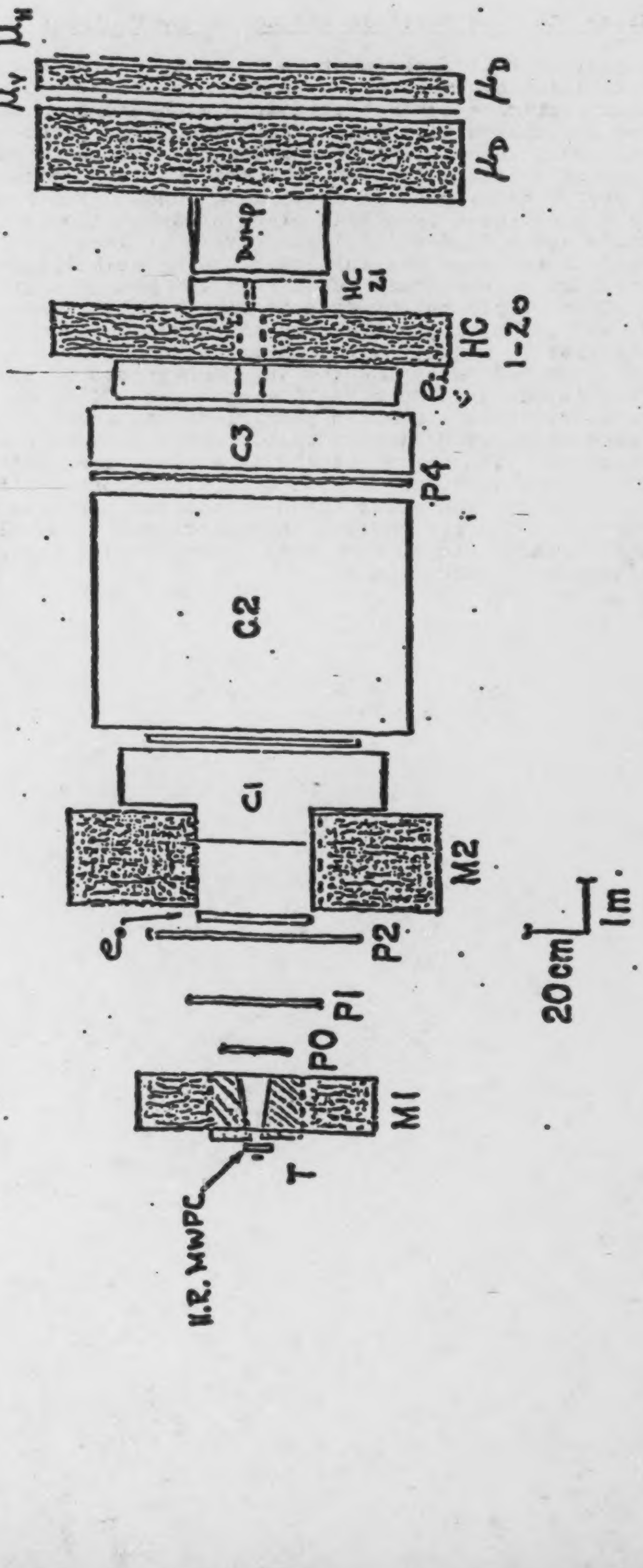
SECTION

III

SUMMARIES OF APPROVED FIXED TARGET EXPERIMENTS

Short descriptions of all approved experiments underway or still to be done are included in this Section. Most summaries were prepared recently by the experimenters themselves; others were obtained from the experimental proposal or agreement.

E-400 Apparatus Plan View

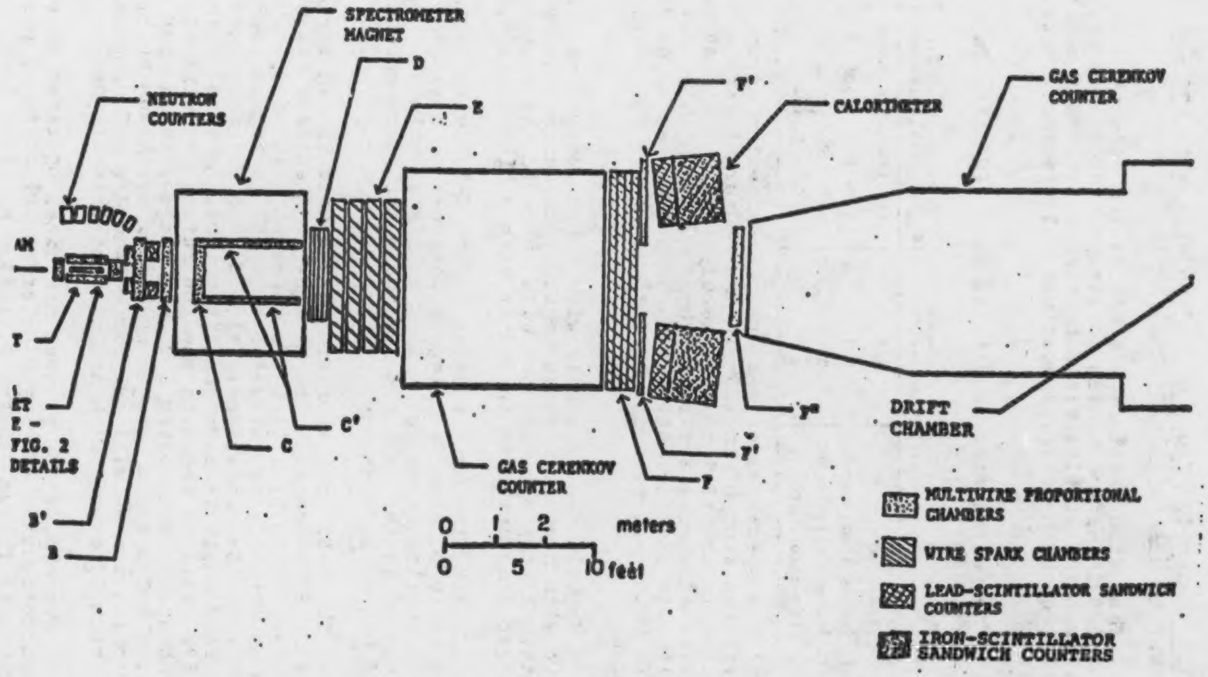

H.R. MWPC
T
M1
PO
P1
P2
e
M2
C1
C2
P4
C3
e2
HC 1-20
HC 21
DUMP
μD
μD
μV
μH
20cm
1m

E-400 (Wiss) Charmed Particle Production by Neutrons

The goal of this experiment is to study the production of charmed particles by incident neutrons. The decay products of the charmed particles are detected in a magnetic spectrometer containing two analyzing magnets and a 7000 wire proportional chamber system. Three multi-celled Cerenkov counters provide charged particle identification. Neutral V's can be reconstructed over a decay path of about 100 inches. Photons and electrons are detected by a lead glass array at the center of the aperture and a lead-scintillator array at large angles. Muons are detected over the full aperture by scintillation hodoscopes, and proportional tubes inserted behind steel hadron filters. This complement of detectors permits the observation of a wide variety of charmed baryon and meson decay modes. In order to assist in rejecting non-charm backgrounds, a system of high resolution MWPC's is located just donwstream of the target. This system is designed to give 70 micron resolution on a secondary vertex from a charmed particle decay and should permit a clean separation of $D^{\pm}$ (and possibly other charmed particles) from background. The target itself is active, consisting of wafers of silicon detectors, which will also provide lifetime information through the observation of charged particle multiplicity growth. The trigger for the experiment is developed in three successive steps, the final one employing a sophisticated trigger processor, the M7.

PLAN VIEW OF THE MPS

E-557 Apparatus Plan View


SPECTROMETER MAGNET
D
E
NEUTRON COUNTERS
F'
CALORIMETER
GAS CERENKOV COUNTER
AM
T
ET
E -
FIG. 2 DETAILS
B'
B
C
C'
GAS CERENKOV COUNTER
F
F'
F"
DRIFT CHAMBER
0 1 2 meters
0 5 10 feet
MULTIWIRE PROPORTIONAL CHAMBERS
WIRE SPARK CHAMBERS
LEAD-SCINTILLATOR SANDWICH COUNTERS
IRON-SCINTILLATOR SANDWICH COUNTERS

E-557 (Malamud) Study of Hadron Jets with the Calorimeter Triggered Multiparticle Spectrometer

This experiment is a study of the structure of events produced in hadron-hadron collisions and having large transverse energy. The multiparticle spectrometer (MPS facility in M6W) is triggered by a large aperture calorimeter covering 2π in azimuth.

The calorimeter is divided into 640 channels arranged in four sections:

	distance from target (m.)	Approx. θ_{cm}(800 GeV)	EM Section R.L.	Hadron Section A.L.
1. "old" unit used in 1981 run	9.4	45^o-130^o	Pb-Sc 16	Fe-Sc 7.5
2. insert into above	9.4	20^o- 45^o	PbGl 20	Fe-Sc 7
3. forward calorimeter	20	3^o- 20^o	PbGl 18	Fe-Gas 10
4. beam calorimeter	30	0^o- 3^o	-	Fe-Sc 10

The spectrometer measures the momentum of most charged particles from 0^o to 135^o in the center of mass. The tracking system in the 1981 run was barely adequate at 400 GeV. With increased energy and replacement of the highly redundant (although inefficient) spark chamber system by drift chambers, more PWC's are needed. A total of 15 new PWC planes will be added.

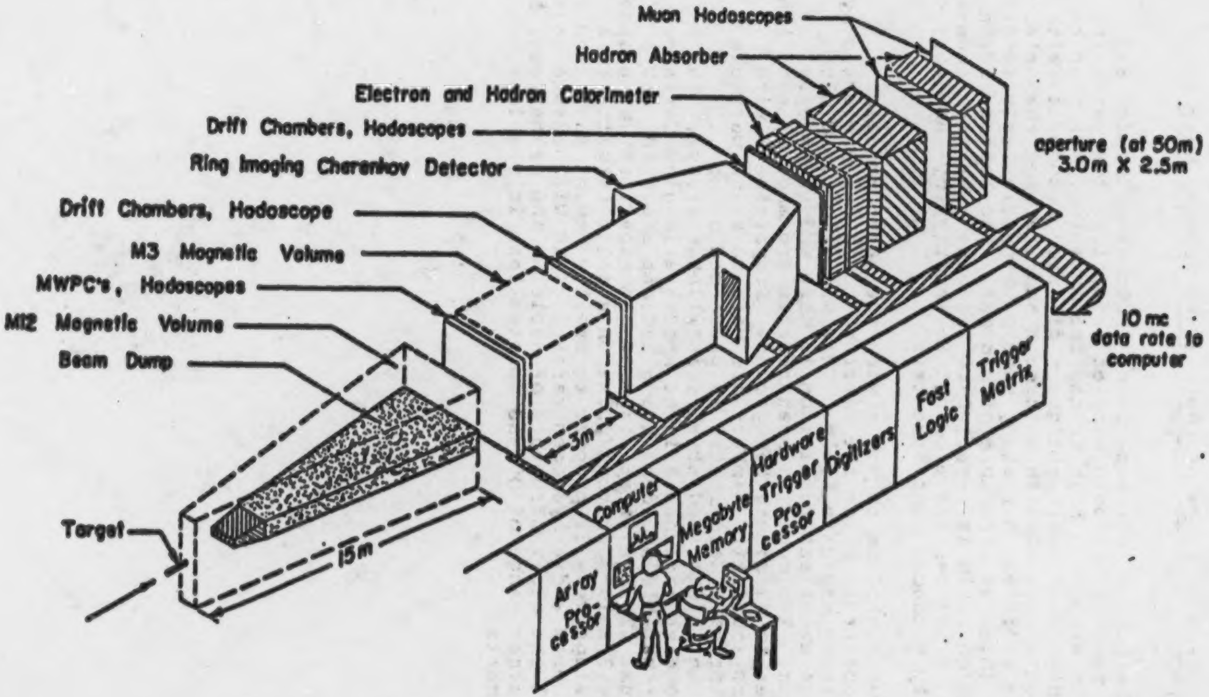
We will run primarily with a hydrogen target, but also take data with heavier targets to study the anomalous nuclear enhancement. A simple γ-detector will surround the target to study target fragmentation in events with a high E_t trigger.

During the next running period E-557 will be completed with a variety of high E_t triggers designed to optimize our study of hard scattering and extending to higher values of E_t than were achieved in the 1981 run. We gain both from more running time and higher beam energy.

The E-557 collaboration had a data run in the Spring of 1981. Problems with the M6 line limited data taking to ~200 hours. In July, 1981 E-672 received Stage I approval. E-672 is essentially an extension of E-557 to higher energies with two important additions: (a) a dimuon trigger; and (b) forward charged particle mass identification. A large toroid, part of E-672, will be added to the apparatus. We will study possible problems in attempting a dimuon trigger in an open geometry. Large PWC's and a trigger processor are being built. For the upcoming run we will trigger on the J/ψ and compare the structure of high E_t events with and without this trigger.

The MPS in the present M6W line, upgraded to 800 GeV using superconducting (Energy Doubler/Saver) magnets, presently is scheduled to run January 1, 1984 - April 1, 1984. Tuneup can be done in the preceding three months using muons while E-609 is being completed. The MPS run will be at 800 GeV, protons only, except for a low energy, low intensity π/e calibration beam. The participants in this combined E-557/672 run are the same.

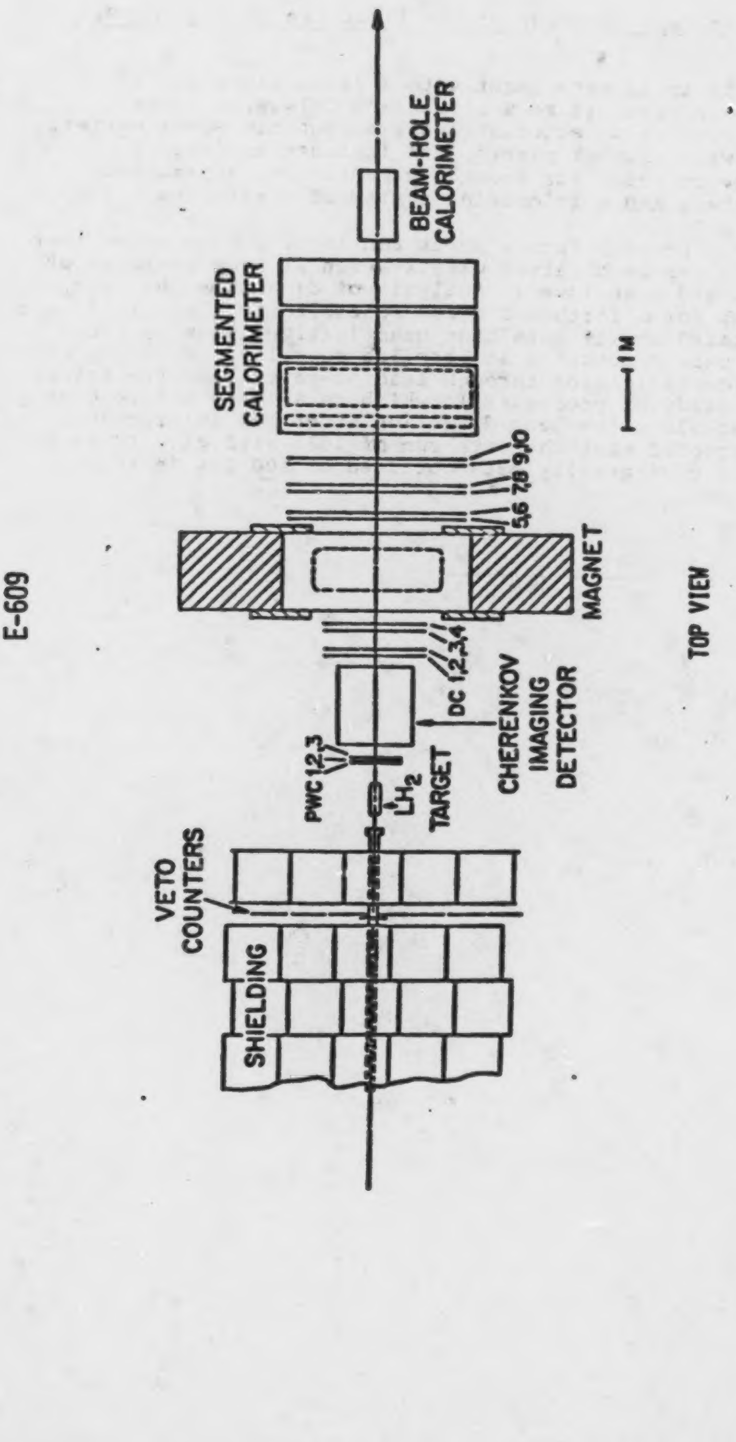
E-605


Muon Hodoscopes
Hadron Absorber
Electron and Hadron Calorimeter
Drift Chambers, Hodoscopes
Ring Imaging Cherenkov Detector
Drift Chambers, Hodoscope
M3 Magnetic Volume
MWPC's, Hodoscopes
M12 Magnetic Volume
Beam Dump
Target
15m
3m
aperture (at 50m)
3.0m X 2.5m
10 mc
data rate to
computer
Trigger Matrix
Fast Logic
Digitizers
Hardware Trigger Processor
Megabyte Memory
Computer
Array Processor

E-605 (Brown) Study of Leptons and Hadrons Near the Kinematic Limits

The goal of our experiment is to study lepton and hadron production (both singles and pairs) for particles produced with very high transverse momentum. We plan to study high-mass quark-antiquark dilepton resonances with excellent resolution in both muon and electron channels. But, in addition, our study should be particularly sensitive to the internal structure of hadrons. The lepton/hadron production ratio is expected to increase near the kinematic limits if hadrons are produced indirectly (by the decay of directly produced constituents).

Our method is to use a wide-aperture magnetic spectrometer in which the first elements are protected by a very strong magnetic field. This magnetic field also provides excellent resolution in mass and transverse momentum. Two momentum measurements are made on each track in order to eliminate background. Proportional wire chambers and drift chambers are used to trace particle trajectories. Calorimetry is performed using lead-scintillator and steel-scintillator arrays. The spectrometer includes a large aperture imaging Cerenkov counter capable of identifying hadrons above 100 GeV/c momentum. In the first stage of the experiment we propose to take 3×10^{12} protons/pulse on a solid target. In a later stage we will propose to use the new M1 pion (and kaon and $\bar{p}$) beam and a hydrogen target. This will enable us to unravel the quark structure of nucleons and mesons over a much larger range of Q^2 and species than in previous experiments.

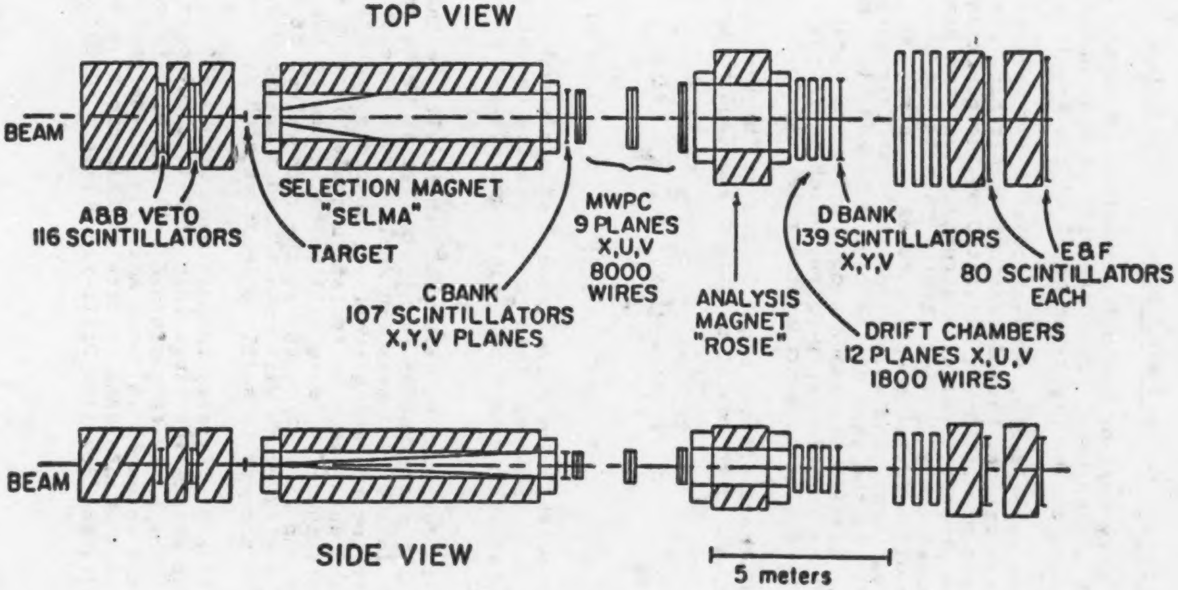

E-609
SHIELDING
VETO COUNTERS
PWC 1,2,3
LH_2
TARGET
CHERENKOV IMAGING DETECTOR
DC 1,2,3,4
MAGNET
5,6
7,8
9,10
SEGMENTED CALORIMETER
BEAM-HOLE CALORIMETER
1 M
TOP VIEW

E-609 (Selove) A Study of the Structure of High-p_t Hadronic Interactions

E-609 is an experiment with a large segmented calorimeter array (8 to 9 steradians CM), with tower structure. The detector includes a magnetic spectrometer, with 13 wire chamber planes, and includes an imaging Cherenkov detector for secondary particles, a beam hole calorimeter, and a triggering system of great flexibility.

Early results from a short run in 1982 have shown that jet pairs can be observed clearly even at beam energies of 400 GeV, and even lower. Analysis of data from that run, and plans for a forthcoming run scheduled for late 1983, are concentrated on (1) obtaining quantitative cross sections for jet pair production at Fermilab energies, (2) study of parton identification through leading-particle correlations, and (3) study of processes in which relatively little energy continues along the beam direction after the interaction. It is expected that the data run of 1983 will give 10 to 50 times the good-quality data obtained at 400 GeV in the initial run.

E-615


TOP VIEW
BEAM
A&B VETO
116 SCINTILLATORS
SELECTION MAGNET
"SELMA"
TARGET
C BANK
107 SCINTILLATORS
X,Y,V PLANES
MWPC
9 PLANES
X,U,V
8000
WIRES
ANALYSIS
MAGNET
"ROSIE"
D BANK
139 SCINTILLATORS
X,Y,V
DRIFT CHAMBERS
12 PLANES X,U,V
1800 WIRES
E&F
80 SCINTILLATORS
EACH
BEAM
SIDE VIEW
5 meters

E-615 (McDonald) Forward Production of Muon Pairs

The primary goal of E-615 is the study of μ-pair production at high X_F with a pion beam. The data will be examined for evidence of QCD corrections to the Drell-Yan model of the μ-pair production.

Previous experiments, in particular E-444 performed by the present collaboration, have demonstrated that high mass ($M_{\mu\mu} > 4$ GeV/c^2) μ-pair production is dominated by the quark-antiquark annihilation process. The pion structure function extracted from the data is approximately $f_\pi(X) = (1-X)$. This is not consistent with an application of the quark counting rules which work well for nucleon structure functions, and which indicate that only even powers of $(1-X)$ should appear in the case of the pion. In addition, E-444 found evidence for significant amounts of longitudinal polarization of the virtual photons for high X_F μ-pairs, which is in contrast to simple models which require pure transverse polarization.

Both of these effects might be due to "higher twist" QCD corrections, as in the model of Berger and Brodsky where

$$f_\pi(X) = \underset{\substack{\nearrow \\ (1+\cos^2\theta)}}{(1-X)^2} + \frac{2}{9}\,\frac{\langle K_T2\rangle}{M^2}\,\underset{\substack{\uparrow \\ (\sin^2\theta)}}{(1-X)^0}$$

The "higher twist" term $\sim 1/M^2$ should show a strong, scale breaking dependence on pair mass. This QCD correction has striking dependence on mass, X, and θ compared to typical corrections which are logarithmic.

E-615 is designed to have good sensitivity to the details of the μ-pair angular distribution at high X. It is being performed in the P-West high intensity π beam (10^9/pulse) with a newly constructed spectrometer incorporating two large-aperture magnets for mass selection and analysis. To isolate a scale breaking term ($\sim 1/M^2$) in the structure function, data will be collected at two different beam momenta, 75 and 250 GeV/c, but at the same values of the scaling variable $\tau = M^2/S$. Runs with both π^+ and π^- beams will verify that the annihilation process is still dominant at high X.

In 1982 a preliminary run was made with a 250 GeV/c π^- beam. The exposure was about five times that of E-444, but only 5% of the goal for E-615. The hardware performed well and will be capable of handling beam rates of 10^9/sec. Analysis of the preliminary run is well underway. Conference reports on this run have been given at Paris (1982), the Fermilab Drell-Yan Workshop (1982) and Moriond (1983).

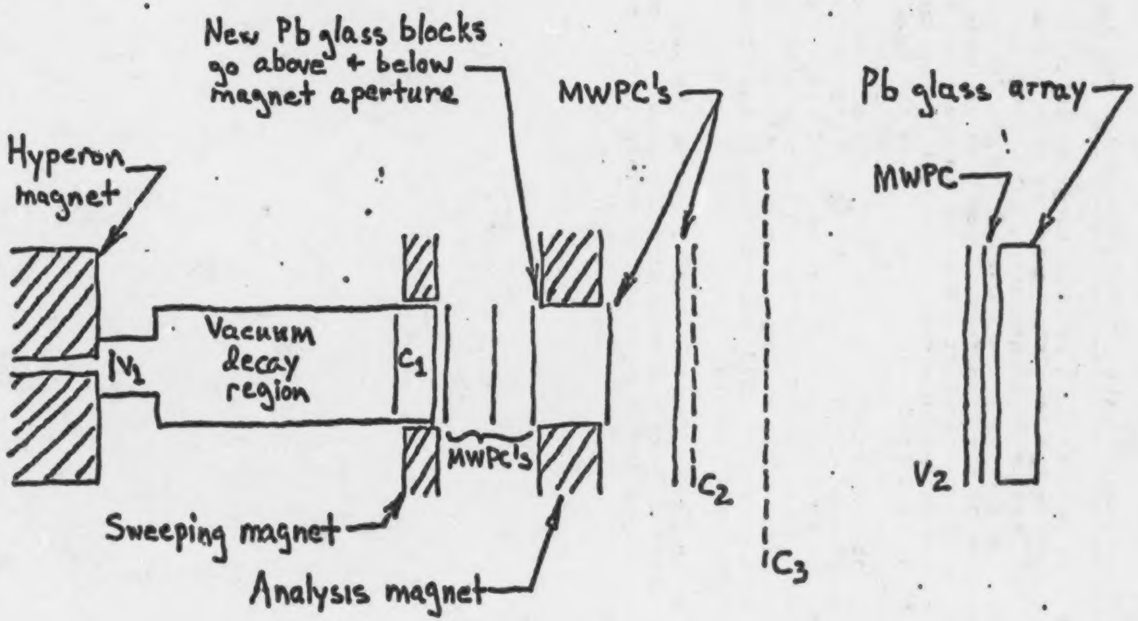

New Pb glass blocks
go above + below
magnet aperture
MWPC's
Pb glass array
Hyperon magnet
MWPC
Vacuum decay region
V_1
C_1
MWPC's
C_2
C_3
V_2
Sweeping magnet
Analysis magnet

Figure 1. E621 Apparatus Plan View

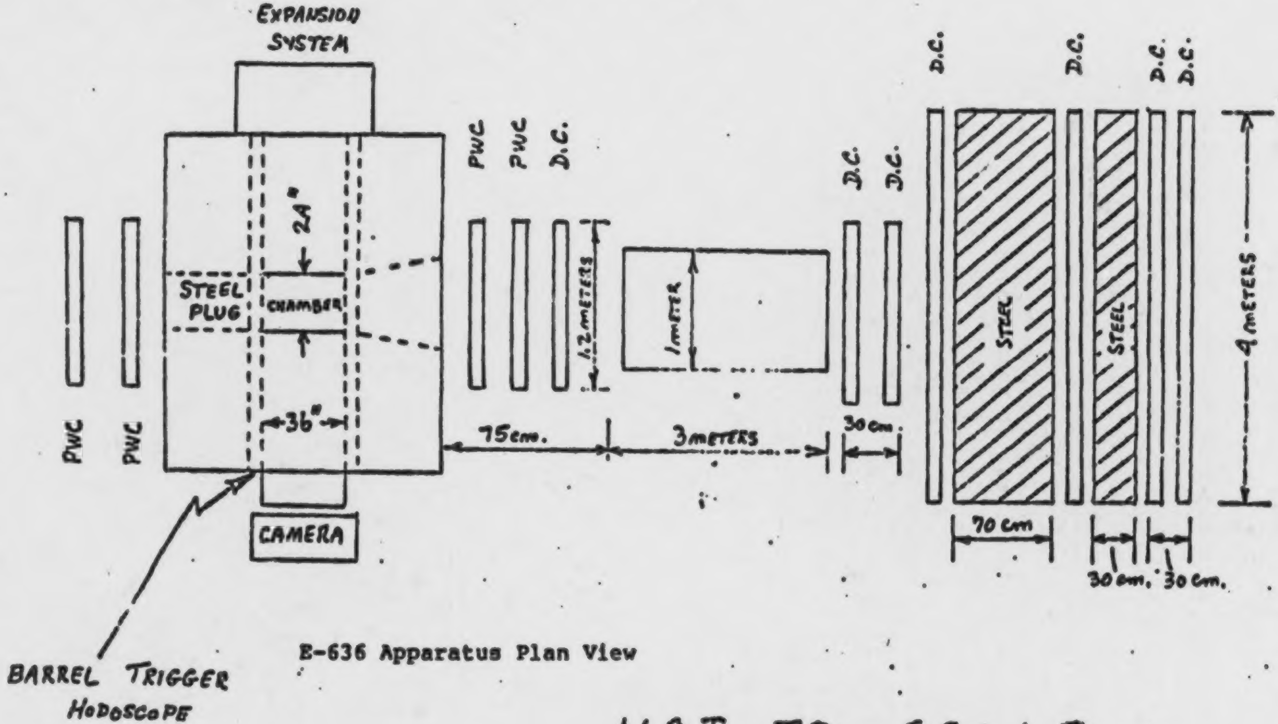
E-621 (Thomson) A Measurement of the CP Violation Parameter η_{+-o}

We have proposed to measure η_{+-o} by measuring the interference between K^o_S and K^o_L decays to $\pi^+\pi^-\pi^o$ near the kaon production target. This interference is dependent on the proper lifetime of the kaons, so that accurate knowledge of the detector's acceptance, as a function of the longitudinal position of decay vertices, is crucial to the measurement. We want to measure this acceptance by also taking data with a separate target 20 meters upstream of the usual hyperon production target. Then the falling proper lifetime exponential will damp out all contributions to the three pion decay rate except that from the K^o_L. Comparison of observed decays with the $\exp(-t/\tau_L)$ K^o_L behavior will tell us the detector acceptance much more accurately than we could calculate it by Monte Carlo techniques. Using this method we hope ultimately to reach an accuracy of $\delta\eta = .25\eta_{+-}$. An initial run with 3×10^6 $K_{\pi 3}$ decays will give $\delta\eta = .003$ - two orders of magnitude better than the current world number.

The apparatus we would use for the initial run is the Vee spectrometer of the Neutral Hyperon Group, with the same configuration as for E-619. Only a few changes are necessary to try to trigger on $K_{\pi 3}$ decays.

E-632 (Morrison) An Exposure of the 15' Bubble Chamber with a Neon-Hydrogen Mixture to a Wideband Neutrino Beam from the Tevatron

It is proposed to study interactions of the wideband neutrino beam of the Tevatron in the 15' bubble chamber filled with a neon-hydrogen mixture. Using a total sample of 70,000 Charged Current (CC) neutrino events the main physics aims are: (a) searches for production of heavy quarks and τ leptons or other unexpected phenomena - the production mechanisms of these and of charmed mesons and baryons will be studied. The event sample is expected to include decays of 7000 charmed particles (including 1200 F^+) and τ^+ particles; (b) the study of quark and gluon fragmentation functions, jets, high P_T phenomena and (c) the measurement of inelastic structure functions. Many other physics topics (resonance and strange particle production, neutral currents, ν_e interactions, etc.) will be studied. Three high resolution cameras will be used to observe the decays of short-lived particles. It is requested that a first sample of 20,000 CC events be obtained as soon as possible after the Tevatron begins operation to search for new phenomena.


EXPANSION SYSTEM
PWC
PWC
STEEL PLUG
CHAMBER
24"
36"
CAMERA
BARREL TRIGGER HODOSCOPE
PWC
PWC
D.C.
1.2 METERS
1 METER
75 cm.
3 METERS
D.C.
D.C.
30 cm.
D.C.
STEEL
D.C.
STEEL
D.C.
D.C.
70 cm
30 cm.
30 cm.
4 METERS

B-636 Apparatus Plan View

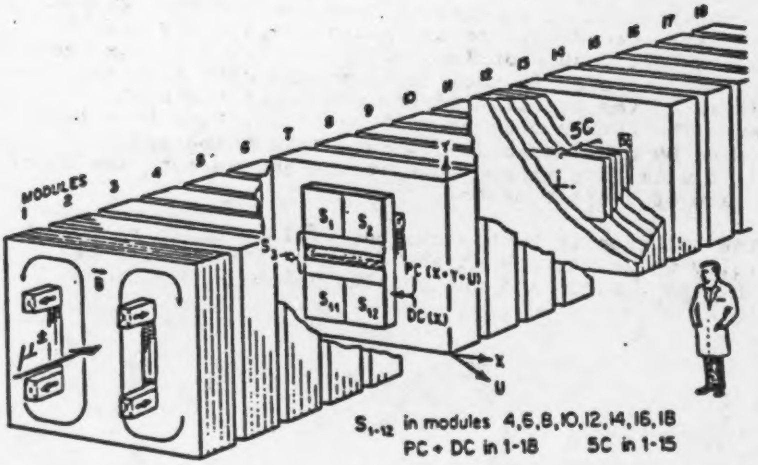
NOT TO SCALE

E-636 (Pless) Study of Beam-Dump Produced Neutrinos

The major goal of E-636 is the establishment of the existence of the tau neutrino. The experimental technique is the combination of a neutrino beam created by a stopped proton beam (beam dump) and an instrumented heavy liquid bubble chamber. Tau neutrinos will be created by the decay of charmed particles in the beam dump and will manifest themselves by the creation of tau mesons in the bubble chamber. The bubble chamber will be illuminated by a laser and viewed by a holographic camera. This holographic technique will make it possible to see and measure the short decay path of the tau meson.

The holographic bubble chamber will be built by Tohoku University while the downstream detector system will be built by the U.S.A. and the Peoples Republic of China.

E-640


MODULES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
$\bar{B}$
$\mu^{\pm}$
S_1
S_2
S_3
S_{11}
S_{12}
PC (X • Y • U)
DC (X)
Y
X
U
5C

S_{1-12} in modules 4,6,8,10,12,14,16,18
PC + DC in 1-18 5C in 1-15

E-640 (Loken) The Multimuon Spectrometer at the Tevatron

The experiment utilizes the Multimuon Spectrometer in the Tevatron muon beam. The distributed target spectrometer magnet provides a high target luminosity with high acceptance over the full target length. The detector is triggered in parallel by ≥ 1, ≥ 2, ≥ 3 muons in the final state using scintillation counter hodoscopes and calorimeter counters.

The initial physics objectives, to be measured simultaneously, are the following:

1. Inelastic muon scattering and determination of nucleon structure functions.
2. Production of high mass vector mesons.
3. Production of heavy quark states.
4. Heavy-lepton production.
5. Study of final states with four or more muons.

The experiment has been approved for 1000 hours of running in the Tevatron muon beam.

E-646 (Baltay) Search for the Tau Neutrino and Study of Prompt Neutrino Production

The Fermilab 15 foot Bubble Chamber will be used, filled with heavy neon (60 to 65% atomic neon + hydrogen). A new prompt neutrino beam is needed with beam dump located 160 meters from the bubble chamber. The running needed is 2 x 10^{18} protons on the dump at Tevatron energies (800 to 1000 GeV). This could be packaged as 100,000 pictures with 2 x 10^{13} protons per pulse or 200,000 pictures with 1 x·10^{13} protons per pulse.

The physics goals are

(i) Search for the ν_τ
  a) Events with visible inflight $\tau^\pm$ decays

  $$\overset{(-)}{\nu}_\tau + \text{neon} \to \tau^\pm + \text{hadrons}$$
  $$\hookrightarrow \text{visible inflight decay}$$

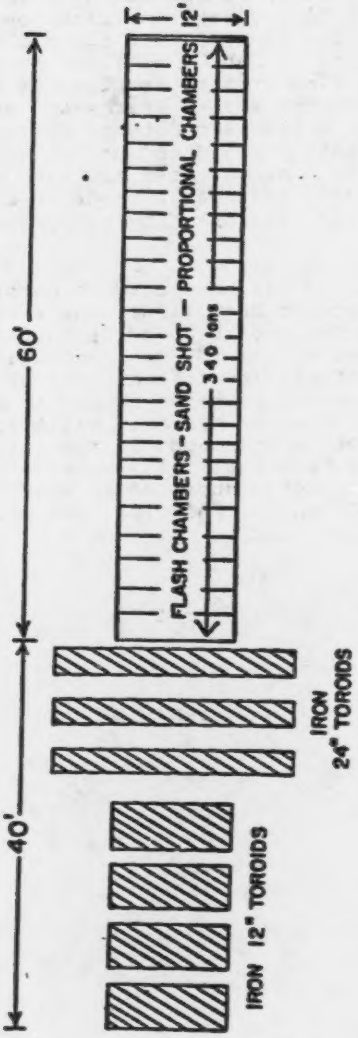
  b) Via events with unusual kinematics using ∼ 1200 ν_τ and $\bar{\nu}_\tau$ interactions in the bubble chamber
  c) Rough measurement of the $\tau^\pm$ lifetime
  d) Search for ν_τ decays (in case the ν_τ has a finite mass)

(ii) Study of ν_e and $\bar{\nu}_e$ interactions
  a) Neutral current/charged current ratio for $\nu_e + \bar{\nu}_e$
  b) Study of $\overset{(-)}{\nu}_e + e^- \to \overset{(-)}{\nu}_e + e^-$
  c) Search for electron type heavy leptons $E^\pm$
  ν_e + neon → $E^\pm$ + hadrons
  d) Universality tests in charged current interactions

(iii) Study of charm and F $\bar{F}$ production in beam dump with ∼ 10,000 "prompt neutrino" events.

(iv) Search for new, unexpected phenomena.

E-649


60'
40'
12'
ν BEAM
FLASH CHAMBERS - SAND SHOT - PROPORTIONAL CHAMBERS
340 tons
IRON
24" TOROIDS
IRON 12" TOROIDS

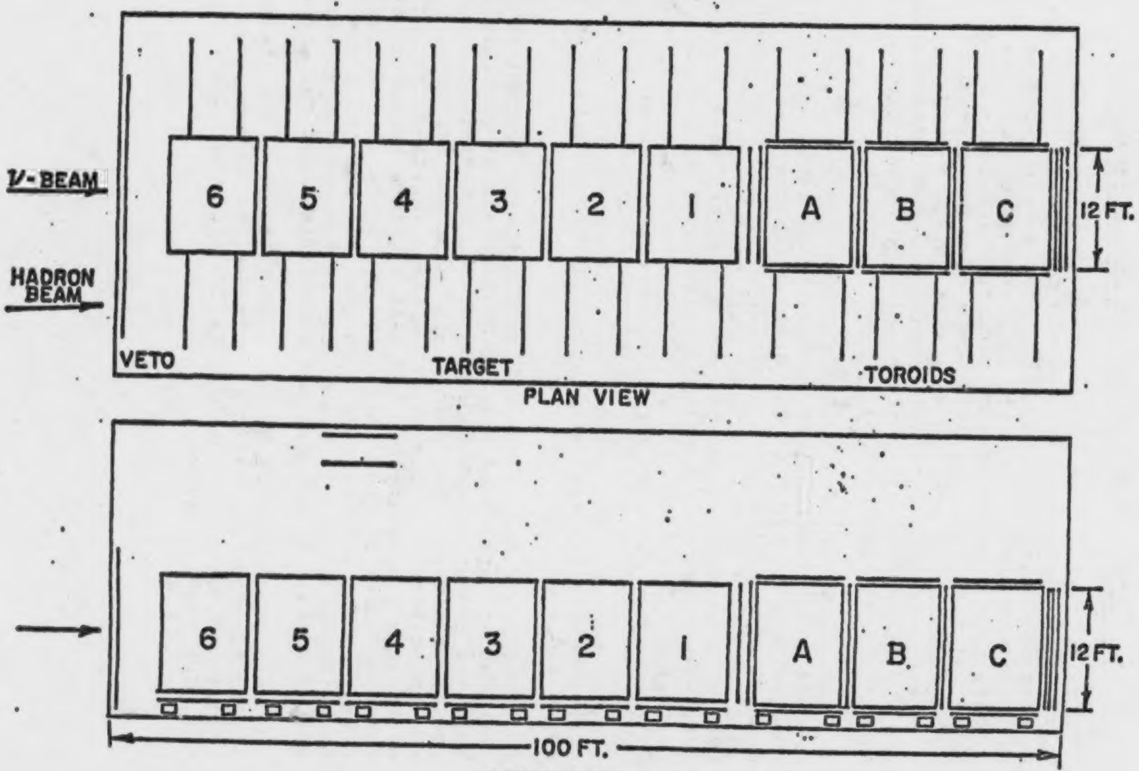
E-649 (Taylor) Proposal to Study Nucleon Structure Functions at High Q^2

The small distance structure of the nucleon is to be measured using high energy neutrino deep inelastic scattering in the fine grained flash chamber-proportional tube calorimeter in Lab C. In this neutrino calorimeter, the resulting fine grained sampling of the recoil shower determines both the shower energy and angle of energy flow. This information allows a determination of the structure functions of both charged and neutral current neutrino interactions in a narrow band neutrino beam. These measurements will test gauge theories of electroweak interactions and confront QCD theory in a new high energy range.

The detector has been used to gather data in both a broad band neutrino beam (1981) and a narrow band neutrino beam (1982). These data have demonstrated a good signal for the process $\nu_\mu + e \rightarrow \nu_\mu + e$ and will yield the x-dependence of weak neutral current structure functions in the neutrino energy range of 50 GeV to 200 GeV. In addition, the detector has been calibrated with beams of hadrons, electrons and muons in the energy range 5 to 125 GeV. The data from E-649 will extend these structure function measurements obtained in 1982 to higher neutrino energies and Q^2 values and will test the theory over a wide kinematic range.

E-652 Apparatus Plan View

LABORATORY 'E' APPARATUS


ν-BEAM
HADRON BEAM
6
5
4
3
2
1
A
B
C
12 FT.
VETO
TARGET
TOROIDS
PLAN VIEW
6
5
4
3
2
1
A
B
C
12 FT.
100 FT.

E-652 (Sciulli) Neutrino Physics at the Tevatron

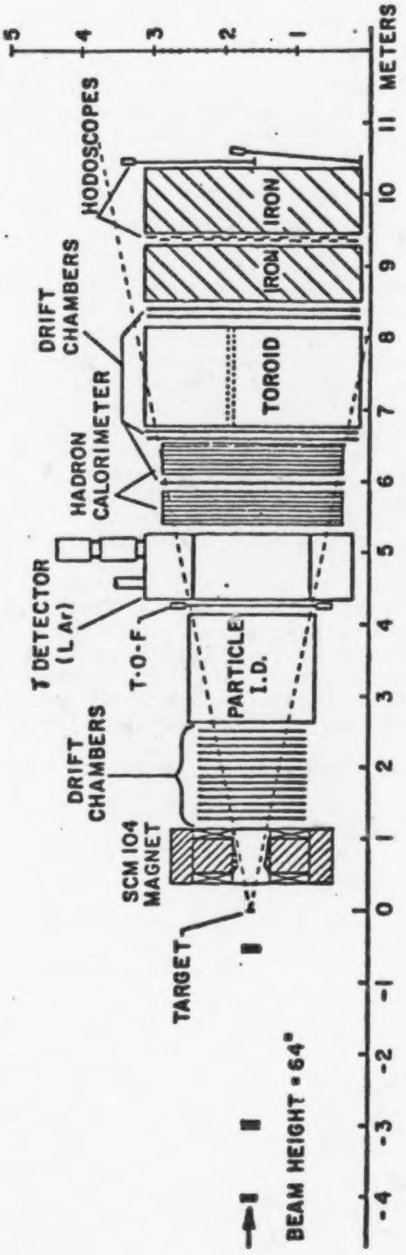
As part of our continuing program in neutrino physics at Fermilab, we propose to use the Lab E detector to investigate neutrino and antineutrino interactions at Tevatron energies. Emphasis is placed on charged current physics with measurements of structure functions and absolute cross sections using data of a Tevatron run combined with our present sample of E616. In addition, we will study neutral current interactions and multimuon events for indications of new phenomena in the higher energy regime accessible at the Tevatron.

An early run of 2×10^{18} protons with the dichromatic beam at the Tevatron would extend the Q^2 range of our data to greater than 500 GeV^2 and allow definitive tests of the present strong interaction theory, QCD. The increased range in Q^2 provided by the Tevatron data will, when combined with E616 data already taken, improve the errors on α_s, the quark-gluon coupling constant, by a factor of 3 to 4. Furthermore the data will provide measurements of $F_L = F_2 - 2xF_1$ or $R = F_L/2xF_1$ in a region where theoretical uncertainties are small. The proposed run would yield about 150,000 neutrino and antineutrino events and lead to measurements of R with statistical errors of $0.03 < \Delta R < 0.1$ for $x < 0.5$.

The Lab E detector and flux monitoring systems at Fermilab are optimized for the measurement of absolute cross sections and structure functions. The detector is a massive device with the target-calorimeter separate from the muon-spectrometer. The experimentally verified resolutions of the Lab E detector and the 1-4% absolute measurements of ν and $\bar{\nu}$ fluxes are sufficient for QCD tests in the present energy regime and are more than adequate for the higher Tevatron energies. In all cases, we believe the systematic errors to be smaller than the expected statistical errors.

The detector will be upgraded to improve its physics and multi-event capabilities. This primarily requires replacement of spark chambers by drift chambers, and a new TDC, ADC readout system.

E-653


BEAM HEIGHT = 64"
TARGET
SCM 104 MAGNET
DRIFT CHAMBERS
PARTICLE I.D.
T-O-F
γ DETECTOR (L Ar)
HADRON CALORIMETER
DRIFT CHAMBERS
TOROID
IRON
IRON
HODOSCOPES
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
METERS
1
2
3
4
5

ELEVATION VIEW

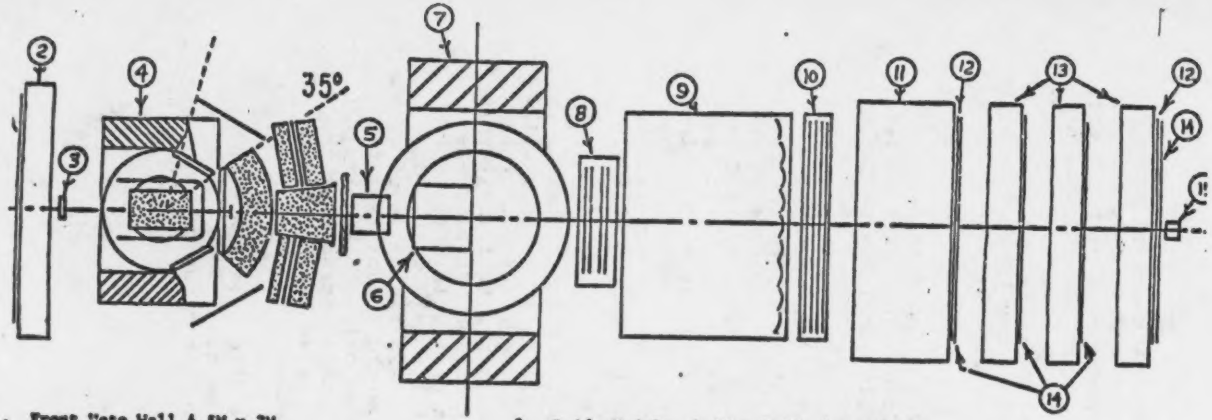
E-653 (Reay) Study of Charm and B Using Hadronic Production in a Hybrid Emulsion Spectrometer

Scientists from Japan, Korea, and the United States have formed a collaboration to perform E-653, a study of hadronic production of charm and beauty using a hybrid emulsion spectrometer.

Lifetimes as short as 2 x 10^{-15} seconds may be measured in the emulsion; the downstream spectrometer will be used to preselect and locate interesting events from interactions in the target of the highest available energy proton beam. The trigger will consist primarily of the presence on line of a several GeV muon originating from near or in the target. Short-lived decays will be tagged off line by a very high resolution vertex detector composed of 21 planes of silicon multistrip detectors, with an estimated precision for resolving secondary vertices of 15 microns transverse to the beam and 200 microns parallel to it. Decay candidates will then be searched for in the thin emulsion target. The anticipated yield from a 100 liter exposure is 15,000 charm and 200 beauty particles; in addition the experiment will have a several- event/nanobarn sensitivity for tau decays, and for new particle states with lifetimes in the range 10^{-10} to 10^{-15} seconds.

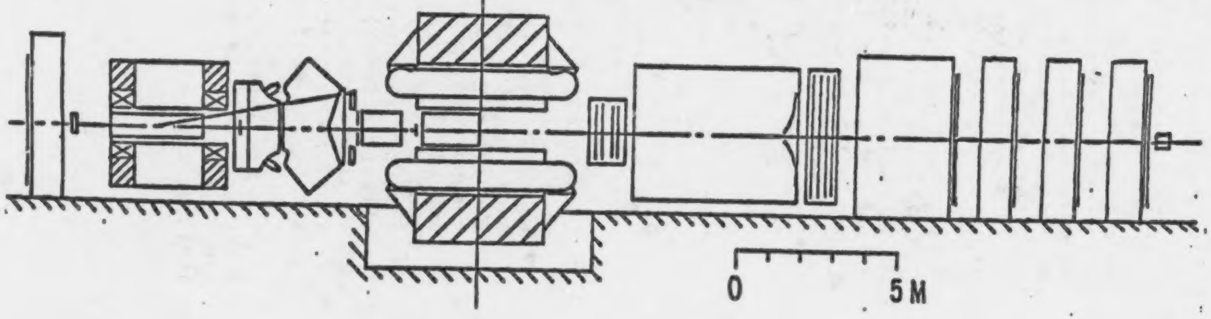
Physics of interest in the charm system includes measuring lifetimes very precisely, resolving existing ambiguities (suggestions of two lifetimes) in D zero decays, and setting stringent limits on $D^o - \bar{D}^o$ mixing. The experiment will do well in studying branching ratios and in looking at excited states of the charm particles.

The apparatus should be ready to record events in mid 1984.



Front Veto Wall 4.5M x 7M
Backscatter Absorber 5M x 8M
Beam Tagging Station, Scin. + MWPC
Vertex Spectrometer (Fig. 12)
MWPC Module, .8M x .8M, 10 planes
MWPC Module, 1.2M x 2.0M, 15 planes
Superconducting CCM, 7.5 Tesla M

8. Drift Module, 1.5M x 2.3M, 4 xy planes
9. Cerenkov Counter, 18 cells
10. Drift Module, 4.0M x 7.0M, 6 planes
11. Fe Hadron Absorber, 5M x 8M x 3M
12. M1, M2 Muon Scin. Counters, 4.4M x 7.0M
13. Concrete Absorbers, 5M x 8M x 1M
14. Proportional Tube Planes, 4.4M x 7M, 6 planes
15. Beam Veto Counter



E-665 (Kirk) Muon Scattering With Hadron Detection

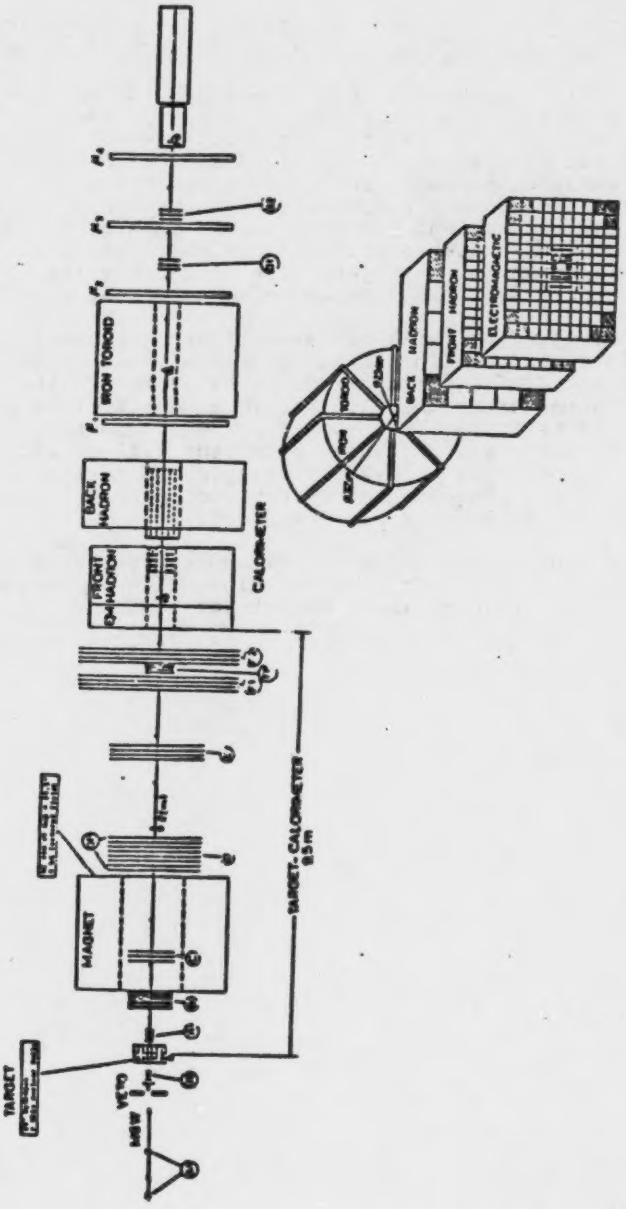
The experiment will study the interactions of muons with beam energies up to 750 GeV in various targets and with the capability of making detailed measurements on the recoil hadrons that emerge from the collision vertex. To this end, the collaboration proposes to combine two large magnets, the EMC Vertex Magnet and the Chicago Cyclotron Magnet in a spectrometer that will be as powerful as any known. We will use this spectrometer in two basic and for the most part complementary ways to explore:

i) the properties of hadrons recoiling from deep inelastic muon collisions in hydrogen and heavy nucleii. It will be possible to study single quark fragmentation and jet physics in the same CM energy region as e^+e^- annihilation experiments at PETRA where gluon radiation has been observed directly. However, in our case fragmentation of the current and diquark jets (not seen in e^+e^-) can be measured with precise knowledge of the exchanged virtual photon direction. Also, by studying the A dependence of these phenomena, we expect to learn new things about the propagation of quarks with defined kinematic properties in nuclear matter. This has not been possible to do in a convincing way in conventional hadron experiments, and is impossible in ep colliders when and if such devices are built.

ii) Complementing the fragmentation studies that we will pursue in hydrogen and heavy nuclear targets will be the study of nucleon structure functions with these same targets. Although the targets are relatively thin, the event yields for structure function studies are respectable up to Q^2 of 100. In particular, the accessible range of Q^2 increases linearly with primary muon energy at small x_{BJ} (<0.02). This region is of great interest in the study of the Q^2 evolution of sea quark structure functions. Here, all experiments are limited by kinematics rather than rates, which means that the Q^2 range is automatically increased by at least a factor of two beyond that presently available.

We may later wish to extend the structure function measurements to larger Q^2 values by means of long hydrogen/deuterium targets located in the place of the streamer chamber.

E-672

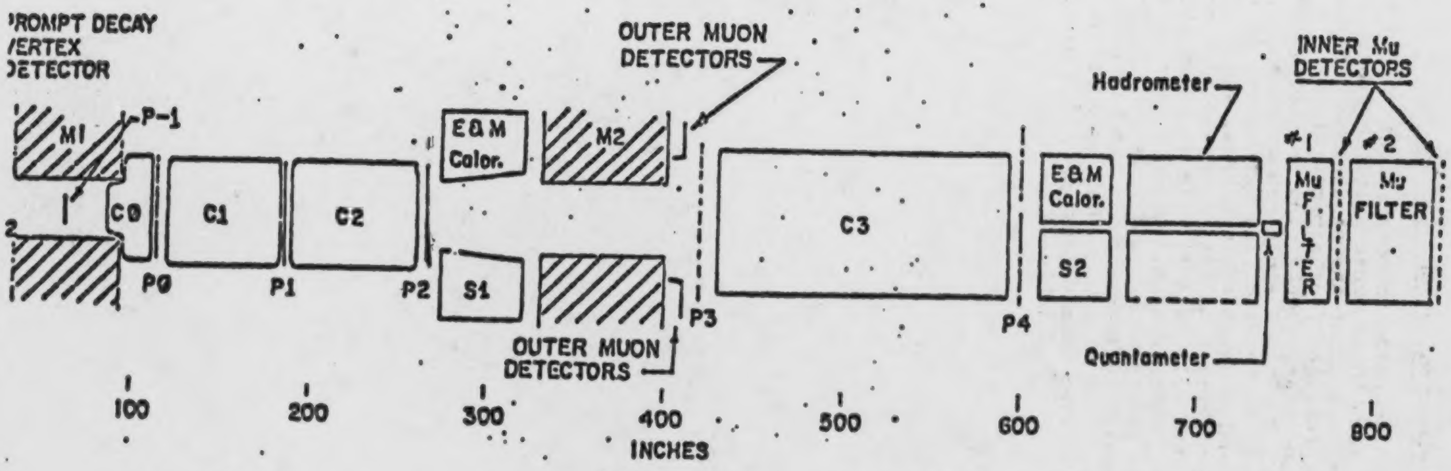

TARGET
MWW
VETO
MAGNET
TARGET-CALORIMETER
9.5m
FRONT HADRON
BACK HADRON
CALORIMETER
IRON TOROID
ELECTROMAGNETIC
FRONT HADRON
BACK HADRON
TOROID

E-672 (Dzierba) Study of Hadronic Final States Produced in Association with High P_t Jets and High Mass Di-Muons

Fermilab experiment E672 is a study of hadronic final states produced in association with high-p_t jets and/or high-mass dimuons in hadron-hadron collisions. These final states will be studied in reactions initiated by 500 GeV/c mesons and protons and 1 TeV/c protons. The goal of this experiment is to make a systematic study of parton-parton scattering and to test QCD predictions of high-p_t jets and/or high-mass dimuon production with particular attention to the accompanying beam jet. The dimuon studies of E672 will be carried out with an open-geometry configuration.

The experiment will use a multiparticle spectrometer (MPS) in a new beamline (M8). The apparatus will be shared by E672 and E706 experimenters. A calorimeter (the existing E557 calorimeter or the E706 liquid argon calorimeter) will be used to trigger on high-p_t jets. A dimuon trigger using a toroid, PWC's and a trigger processor will be included. A forward calorimeter to measure energies of particles in the beam jet and a ring-imaging Cerenkov counter to identify beam jet particles will also be added.

The implementation of the dimuon trigger will be tested using the E557 MPS in the M6 beamline. The accompanying figure shows the experiment layout for that run.


ROMPT DECAY
/ERTEX
)ETECTOR
M1
P-1
1
2
C0
C1
C2
P0
P1
P2
E&M Calor.
S1
M2
OUTER MUON DETECTORS
OUTER MUON DETECTORS
P3
C3
P4
E&M Calor.
S2
Hadrometer
Quantameter
INNER Mu DETECTORS
#1
#2
Mu FILTER
Mu FILTER
100
200
300
400
500
600
700
800
INCHES

E-687 Apparatus Plan View

E-687 (Butler) Photoproduction of Charm and B

This is a photo-production experiment in the new Wide-Band Photon Beam to be constructed in Proton East. It represents a continuation of the studies of E-87 and E-401 which have so far revealed four aspects of the photo-excitation of states containing charmed quarks: charmed mesons D^o, $\bar{D}^o$, D^+, D^-; charmed baryons Λ_c, $\bar{\Lambda}_c$; J/ψ and ψ' production. The goal of the experiment is to continue these studies using the new beam, which will have substantially less neutral hadron background, and use the higher energies that will be available to begin the study of states containing bottom quarks. These states will be detected in a new spectrometer, which is similar in many respects to our existing spectrometer but has roughly four times the aperture. It will also have more highly segmented e/γ detection, improved muon detection, and a prompt vertex detector.

E-690 Apparatus Plan View.

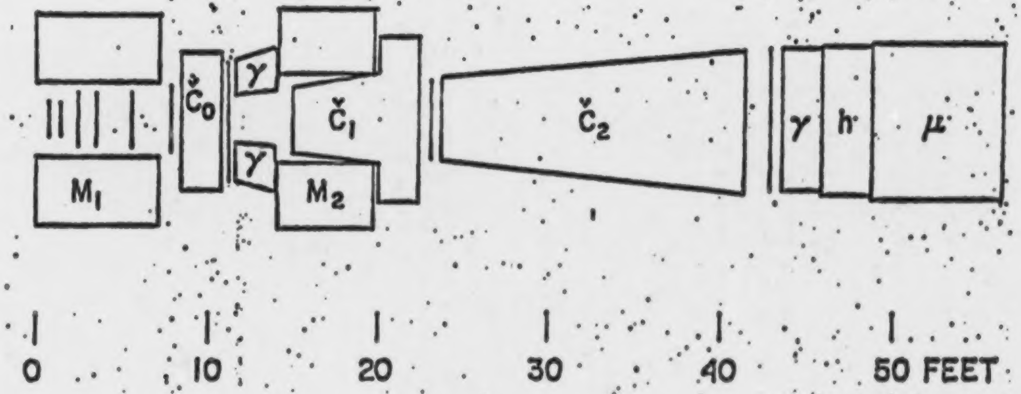
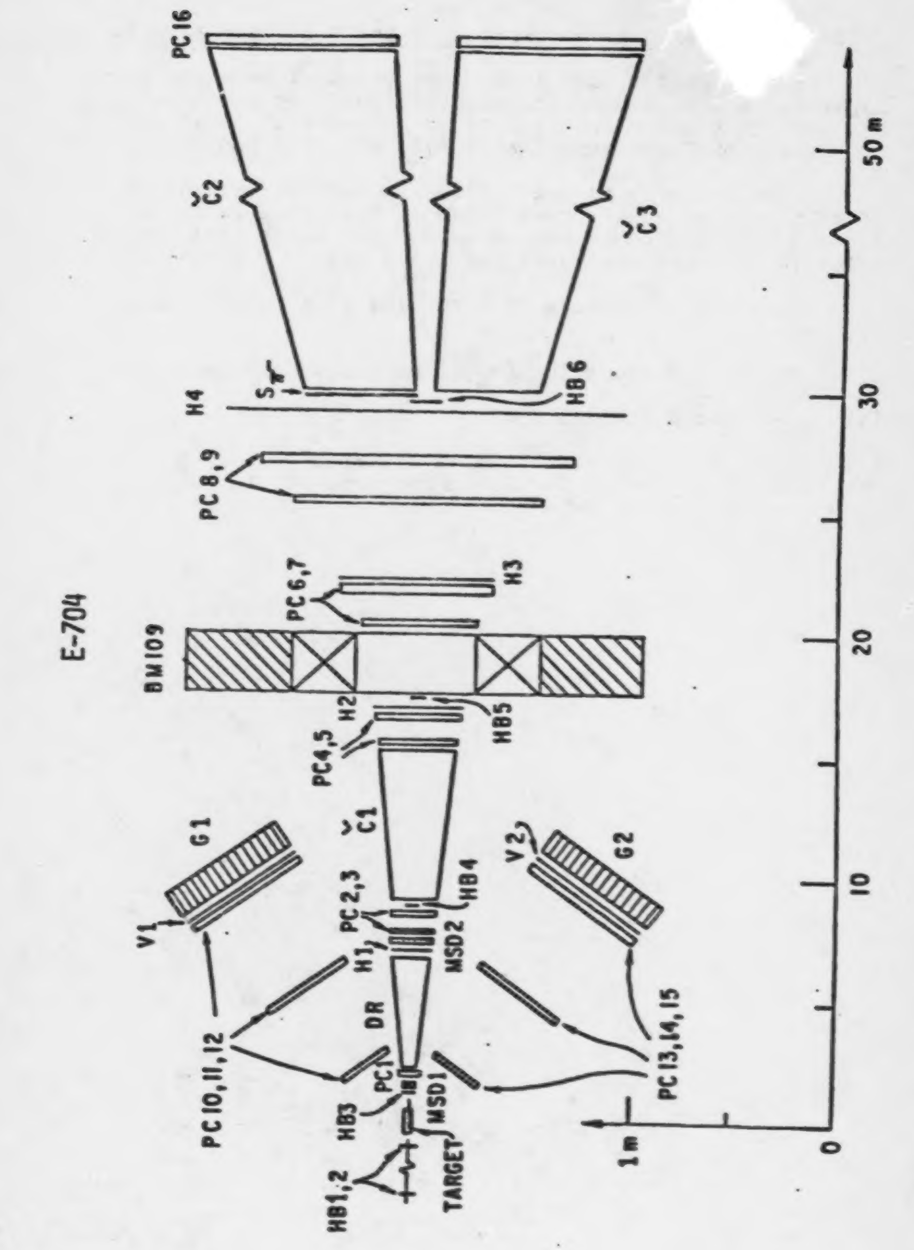

M_1
$\check{C}_0$
γ
γ
$\check{C}_1$
M_2
$\check{C}_2$
γ
h
μ
0
10
20
30
40
50 FEET

FIG. 2

E-690 (Knapp) Study of Charm and Bottom Production

The purpose of this experiment is to study the production and decay of charm and bottom particles. Assuming $c\bar{c}$ production by hadrons of 10^{-3} and $B\bar{B}$ of 10^{-6} we believe we can obtain $\sim 10^4$ $c\bar{c}$ fully reconstructed and fully isolated events per hour and a few $B\bar{B}$ per hour. States will be identified by the final state particles and mass. Branching ratios and lifetimes ($>5\times10^{-13}$ seconds) can be measured. A future improvement of adding a vertex detector would improve lifetime measurements.

The experiment uses a two-magnet spectrometer which has large acceptance for charged and neutral hadrons and for electrons and photons - with emphasis upon the kinematic regions involving target and projectile dissociation. The drift chambers, Cerenkov counters, calorimeters, etc. in the spectrometer are all capable of operating at event rates of 10^6 per second. The spectrometer information is processed by a new, unique processor that can accept a full new event every 10 μsec even though it may take several tens of μsec to reconstruct an event. Quantities formed from momenta and mass for charged particles (energy and direction for neutrals) are used to make various triggers of choice to transfer raw and/or processed event information to an on-line computer and its associated magnetic tape drive. A 20 MHz beam of up to full accelerator energy is required.


E-704
TARGET
HB1,2
HB3
MSD1
PC1
DR
H1
PC 2,3
MSD2
HB4
PC 10,11,12
PC 13,14,15
V1
G1
V2
G2
Č1
PC4,5
H2
HB5
BM109
PC 6,7
H3
PC 8,9
H4
S_π
HB6
Č2
Č3
PC16
1 m
0
10
20
30
50 m

E-704 (Yokosawa) Experiments with the Polarized Beam Facility

Experiment 704, the Integrated Proposal on First Round Experiments with the Polarized Beam Facility, constitutes a proposal to simultaneously perform substantial parts of previously proposed experiments 674, 676, 677 and 678.

Prior to carrying out E-704, a polarized beam line (E-581) must be constructed. The initial plan is for a 200-GeV/c conventional magnet beam line, which will obtain polarized protons from decaying lambdas.

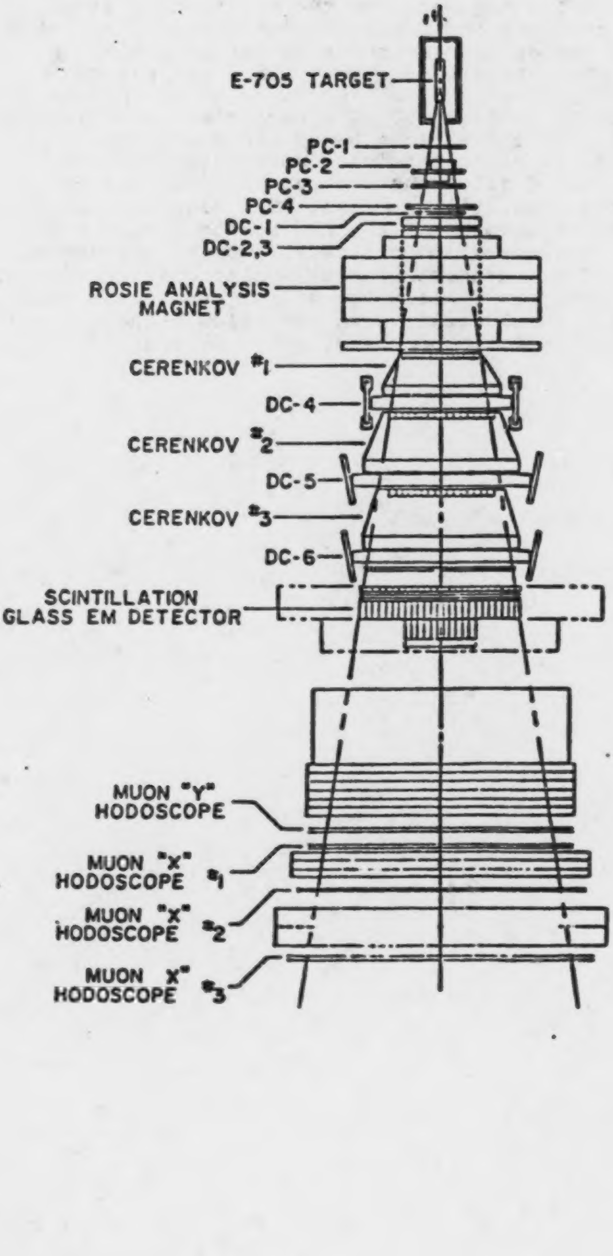
The first 1200 hours of beam time will be allocated as follows:

i) First 300 hours for $\Delta\sigma_L^{Tot}(pp)$ including tuning.

ii) 300 hours for $\Delta\sigma_L$ $(\bar{p}p)$.

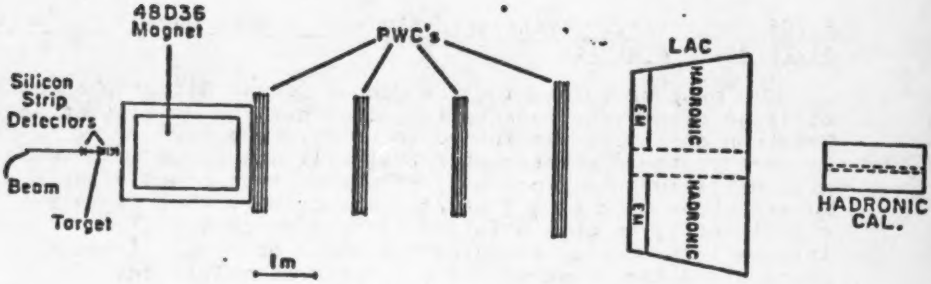
iii) 600 hours for simultaneous measurements using a hydrogen target for A_N in large-p_t π^0, large-x $\pi^\pm$, and Lambda production.

E-705


E-705 TARGET
PC-1
PC-2
PC-3
PC-4
DC-1
DC-2,3
ROSIE ANALYSIS MAGNET
CERENKOV #1
DC-4
CERENKOV #2
DC-5
CERENKOV #3
DC-6
SCINTILLATION GLASS EM DETECTOR
MUON "Y" HODOSCOPE
MUON "X" HODOSCOPE #1
MUON "X" HODOSCOPE #2
MUON X" HODOSCOPE #3

E-705 (Cox) A Study of Charmonium and Direct Photon Production by 300 GeV/c Antiproton, Proton, π^+ and π^- Beams

This Tevatron experiment will use the large aperture spectrometer of E-537 augmented by the addition of large angle Cerenkov counters and a unique high resolution photon electromagnetic shower counter to study direct photon production and charmonium production with a variety of particle beams ($\bar{p}$, p, π^+, π^-) at 300 GeV/c in the Proton West High Intensity Laboratory. The comparison of direct photon production by the various beams along with the observation of final state particles associated with the direct photons should allow the separation of $q\bar{q}$ and gq components of the production process. The high resolution, high statistics measurement of the charmonium states will not only allow the separation of the various $\gamma\psi$ states but also the detailed measurement of the angular distribution of the charmonium decays. Finally the unique resolution that this spectrometer should achieve should allow higher sensitivity searches for other heavy quark states.

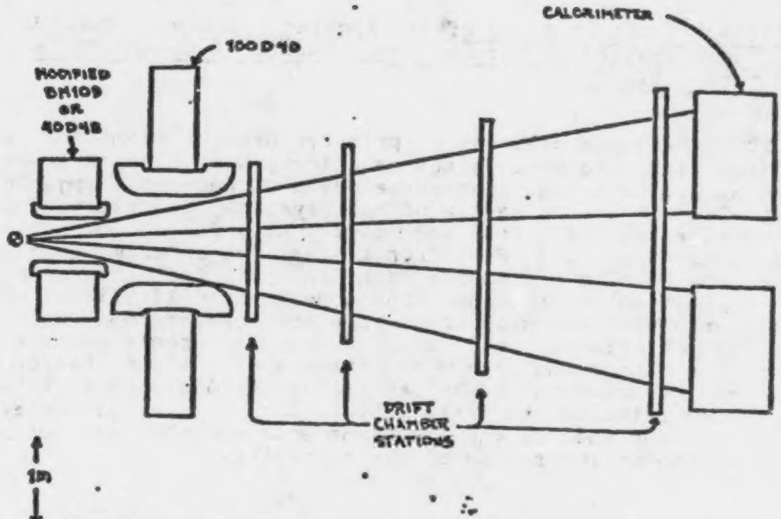

48D36
Magnet
PWC's
LAC
Silicon
Strip
Detectors
Beam
Target
HADRONIC
EM
HADRONIC
EM
HADRONIC
CAL.
1m

Experimental layout for E706

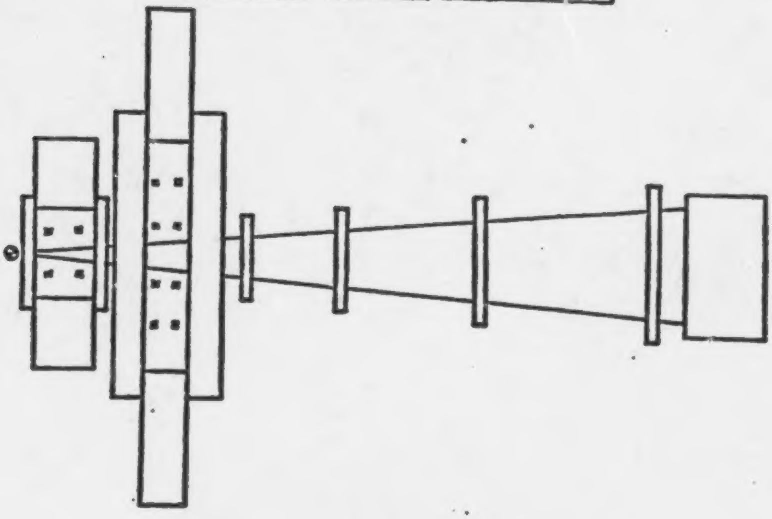
E-706 (Slattery) Systematic Study of Direct Photon Production at Tevatron Energies

We propose to examine the production of direct photons at large transverse momenta in hadron-nucleon collisions at Tevatron energies. We intend to construct a new large-acceptance spectrometer that will enable us to measure with precision the properties of events that contain one or more photons with $p_T \gtrsim 5$ GeV/c. The primary goal of this experiment is to obtain information on quark and gluon interactions through studying the yield of single direct photons and their accompanying hadrons in collisions of π^+, π^- and p with nucleons. In particular, we will determine the gluon structure functions of the pion and the nucleon from rates extracted for the fundamental reactions $qg \rightarrow q\gamma$ (Compton process) and $\bar{q}q \rightarrow g\gamma$ (Annihilation process); we will also measure the fragmentation properties of the gluons and quarks that accompany photons in these reactions. We expect, in addition, to extract the signal for the simultaneous production of two primary photons in order to gain information on the $\bar{q}q \rightarrow \gamma\gamma$ process. This elementary reaction, expected to occur at approximately the level of $\bar{q}q \rightarrow \ell^+\ell^-$, offers, in parallel with the Drell-Yan process, a particularly clean test of predictions from QCD. A unique feature of our proposed investigation is that we will be able to carry out a direct comparison of these two fundamental processes by comparing our $\gamma\gamma$ and e^+e^- triggered events.

The experiment is to be performed using 400 GeV/c protons, 530 GeV/c $\pi^\pm$ and protons, and 800 GeV/c protons, with beam intensities $\gtrsim 10^7$ per second. Assuming a 25% duty factor for the Tevatron, we require 2400 hours of beam time to complete our investigation; of this, 400 hours will be employed for setup and debugging of the apparatus.


CALORIMETER
100D40
MODIFIED BM109 OR 40D48
DRIFT CHAMBER STATIONS
1m
2m

DETECTOR ELEVATION (NON-BEND VIEW)



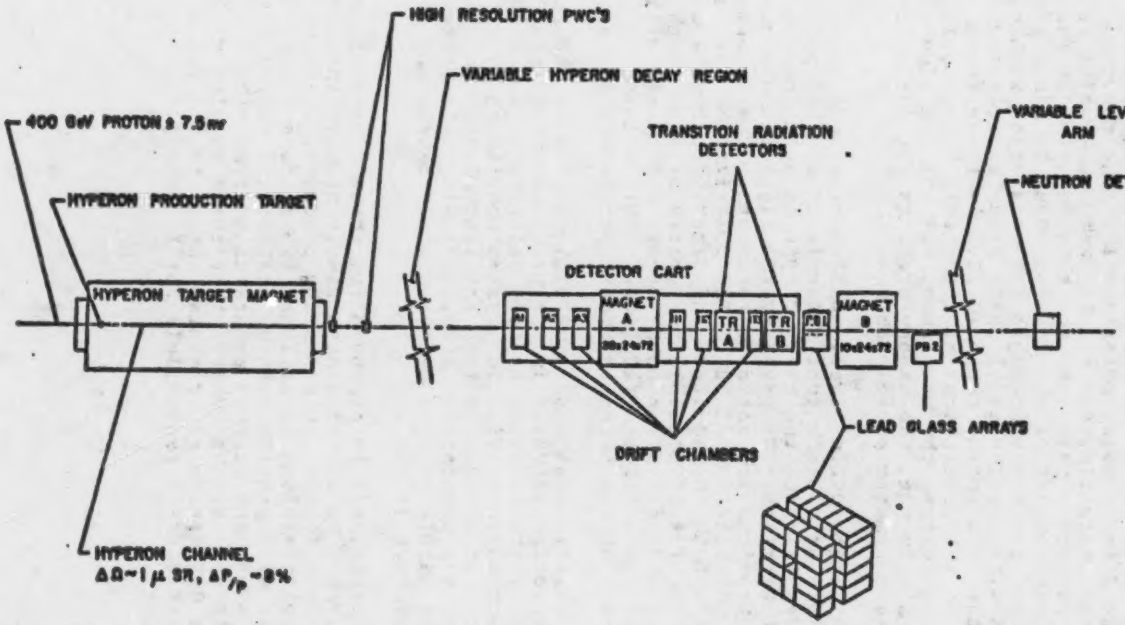
DETECTOR PLAN VIEW (BEND VIEW)

E-711 Plan view and elevation of the spectrometer.

E-711 (Levinthal) A Study of the Angular and Energy Dependence of Constituent Scattering through Measurements of the Reaction $p + N \to h_1 + h_2 + X$.

The experiment will use a primary proton beam and a beryllium target to measure the reaction p+N to h_1+h_2+X where h_1 and h_2 are both high transverse momentum hadrons - roughly back-to-back in the pN centre of mass system. By determining the angular distribution and mass dependence of the cross-section of the di-hadron system, the experiment will extract the angular and energy dependence of the underlying hard constituent scattering. The experiment will trigger on events containing two high transverse momentum hadrons using a hadron calorimeter and uses a magnetic spectrometer to measure the charge and obtain the momenta of the two hadrons with good resolution. The apparatus is designed to take interaction rates up to 5×10^7 by using the spectrometer magnet to sweep most of the low transverse momentum particles away from the active region of the apparatus.

E-715


HIGH RESOLUTION PWC'S
VARIABLE HYPERON DECAY REGION
400 GeV PROTON ± 7.5 mr
HYPERON PRODUCTION TARGET
HYPERON TARGET MAGNET
HYPERON CHANNEL
ΔΩ~1 μ SR, ΔP/P ~8%
DETECTOR CART
MAGNET A
MAGNET B
10x24x72
TR A
TR B
PB1
PB2
TRANSITION RADIATION DETECTORS
DRIFT CHAMBERS
LEAD GLASS ARRAYS
VARIABLE LEVER ARM
NEUTRON DETECTOR

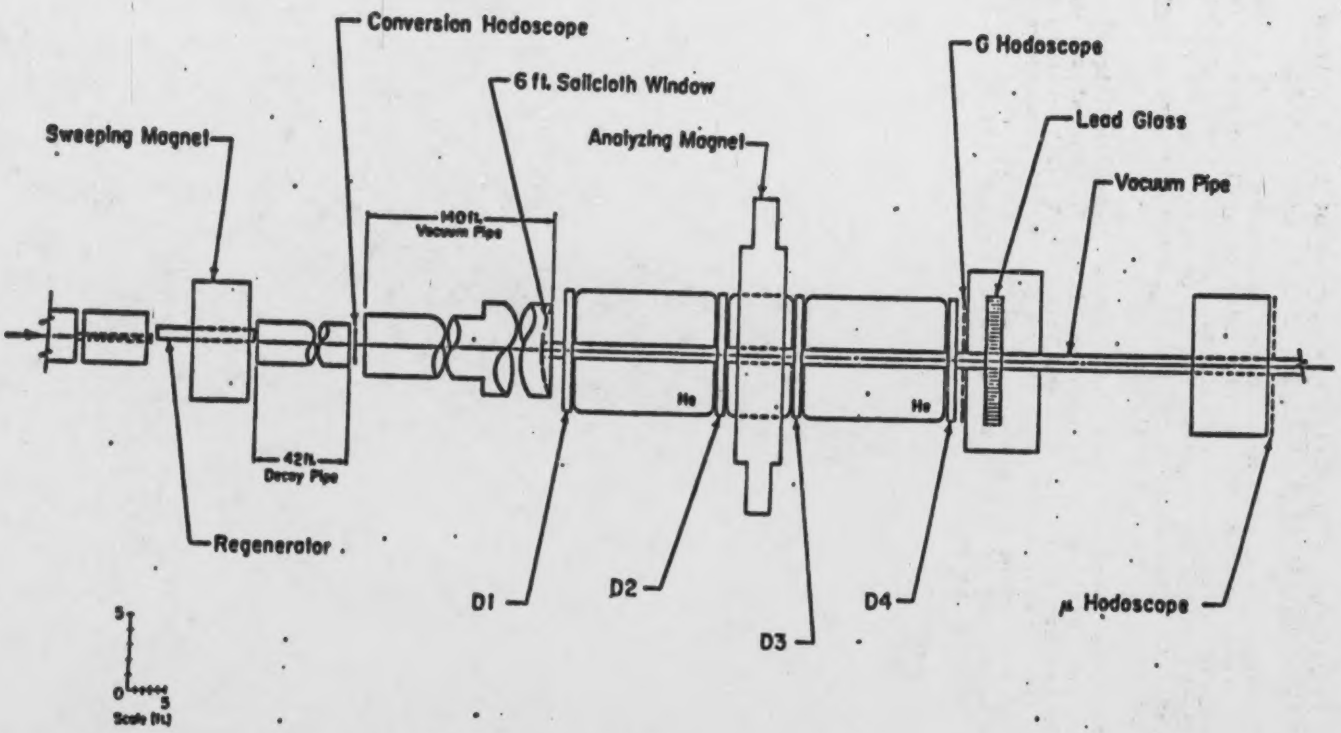
E-715 (Cooper) Precision Measurement of the Decay $\Sigma^- \to ne^-\nu$

This is an experiment to make a definitive study of the beta decay $\Sigma^- \to ne^-\nu$ using polarized Σ^-. Four previous experiments, totalling 400 events, measure a value for the electron asymmetry parameter for this decay which disagrees with the predictions of the Cabibbo model by six standard deviations. These measurements are consistent with each other and with unpolarized Σ^- beta decay experiments if the sign of the form factor ratio (Ga/Gv) is taken to be opposite to the predictions of the theory (the unpolarized experiments measure the magnitude, but not the sign of Ga/Gv). Simply put, the theory predicts the decay to be V+A and all measurements agree with V-A.

In order to definitively confirm or reject these observations we will collect a sample of 100,000 polarized Σ^- beta decays using the charged hyperon beam in Proton Center at Fermilab. We have several significant advantages over the previous low energy experiments. The Σ^- beam has a measured polarization of 50%. The polarization can be controlled, both in magnitude and direction, to allow detailed studies of possible systematic errors. With the use of a tracking neutron calorimeter, all events will be completely reconstructed (1C fits). This allows measurements of all three asymmetry parameters (n, e^-, ν).

The experimental apparatus will consist of the charged hyperon spectrometer used in our previous experiment E-497 augmented by the tracking neutron calorimeter and a two level electron identification system consisting of transition radiation detectors and lead glass. We anticipate π/e separation of 30,000/1 with this system yielding a sample of beta decays with 3% background from hadronic decays ($\Sigma^- \to n\pi^-$).

The experiment is approved for three months of running at 400 GeV/c. We expect a data sample of more than 100,000 analyzed beta decays divided among positive, negative and zero Σ^- polarizations in at least two different directions. These data will provide a large statistical sample with which to study and correct apparatus bias or other systematic errors. We believe that these results will provide a definitive experimental answer to the V,A nature of the weak current responsible for Σ^- beta decay.


Conversion Hodoscope
6 ft. Sailcloth Window
Sweeping Magnet
Analyzing Magnet
G Hodoscope
Lead Glass
Vacuum Pipe
140 ft. Vacuum Pipe
42 ft. Decay Pipe
He
He
Regenerator
D1
D2
D3
D4
μ Hodoscope
5
0
5
Scale (ft.)

E-731 Apparatus Plan View

E-731 (Winstein) A Precision Measurement of the Magnitude of the CP Violation Parameter ϵ'/ϵ in the Neutral Kaon System.

The experiment will measure the magnitude of ϵ'/ϵ in the neutral kaon system to a precision of .001 to search for evidence of direct CP violation. As in the previous experiment (Fermilab E-617) the information on $|\epsilon'/\epsilon|$ is obtained from a measurement of $|\eta_{+-}/\eta_{oo}|$ and the appropriate relation $|\eta_{+-}/\eta_{oo}| = 1 + 3|\epsilon'/\epsilon|$.

The experiment will use the double beam technique of E-617: two distinct K_L^o beams (one with a "regenerator") are used to measure first $|\rho/\eta_{oo}|$ and later $|\rho/\eta_{+-}|$. The ratio of these two measurements is $|\eta_{+-}/\eta_{oo}|$. E-731 represents an improved experiment and beam which combine about equally to yield a factor of x40 in the observed rate of the $K_L^o \rightarrow \pi^o\pi^o$ decay compared to E-617.

3. What have been the program's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?

Answer: For the period specified in the question, the Fermilab research programs have been exclusively in fixed-target physics. Consequently, the answer to this question is the same as the response given above to the corresponding question concerning Fermilab as a whole, i.e. question number 2.0.1.

4. For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the program. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: Funding profiles for the Fermilab fixed-target program from FY 1981 through FY 1985 are given in the table below. These funds are all provided by the DOE high energy physics program, with the sole exception of the In-House Energy Management funds provided under DOE Departmental Administration. The sums shown are actuals for FY 1981 through FY 1983 and estimates for FY 1984 and FY 1985. The physics research activities of Fermilab staff are all in-house research; no out-of-house research is performed by Fermilab staff. The Fermilab research staff does devote a fraction of their time to activities which assist the research program of outside users at Fermilab.

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$76,911	$85,205	$92,274	$91,057	$117,460
In-House Research	5,999	6,252	8,542	9,407	10,000
Operations	50,153	59,150	68,300	75,100	88,700
Other Operating Expenses	20,759	19,803	15,432	6,550	18,760
Capital Equipment	15,767	14,733	17,348	16,550	19,100
Plant	22,900	19,440	25,860	21,500	20,300
Energy Saver	17,300	6,500	--	--	--
Tevatron II	--	6,000	18,000	13,000	12,000
Accel. Improv.	3,400	3,900	4,500	5,100	5,300
General Plant	1,400	1,840	2,460	2,500	3,000
In-House Energy Management	800	1,200	900	900	--
Total DOE Funding	$115,578	$119,378	$135,482	$129,107	$156,860

5. How much of the program's for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: For the period specified in the above question, the Fermilab research programs have been exclusively in fixed-target physics. Consequently, the answer to this question is the same as the response given earlier to the corresponding question concerning Fermilab as a whole, i.e. question number 2.0.4.

6. **For the period FY 1981 operation) - FY 1985, please provide actual and estimated staffing levels for the program.**

   Answer: The staff levels associated with the Fermilab fixed-target program are as follows:

				Estimate	Estimate
	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Full Time Equivalents	1939	1910	1914	1770	1975

7. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

   Answer: For the period specified in the above questions, the Fermilab research programs have been exclusively in fixed-target physics. Consequently, the answers to these questions are the same as the responses given earlier to the corresponding questions concerning Fermilab as a whole, i.e. question number 2.0.6.

8. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

   Answer: For the period specified in the above questions, the Fermilab research programs have been exclusively in fixed-target physics. Consequently, the answers to these questions are the same as the responses given earlier to the corresponding questions concerning Fermilab as a whole, i.e. question number 2.0.7.

9. **How many research proposals have been submitted over the past five years (or since the beginning of operation if later), and how many of these have been approved?**

   Answer: During the past five years, 109 research proposals for fixed-target experiments were submitted to Fermilab. Forty-two of these were approved.

10. **How many university personnel (i.e., faculty and students) have participated in the program over the past five years?**

    Answer: During the past five years, fixed-target experiments involving the participation of about 950 university-based researchers (faculty and students) have been carried out using Fermilab research facilities.

11. **How many industrial researchers have participated in the program over the past five years?**

    Answer: No industrial researchers have participated in fixed-target experiments at Fermilab.

12. How many researchers from foreign institutions have participated in the program over the past five years?

Answer: About 280 physicists from foreign institutions have been involved in fixed-target experiments using Fermilab facilities over the last five years.

13. What are the future possibilities for this program (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: As discussed in response to an earlier question, there are no specific plans at this time for major development of the Fermilab fixed-target capabilities beyond those being provided under the Tevatron II project. After operating experience is gained at 1000 GeV, experimental results will undoubtedly point to the need for new investigations which will require new or upgraded detectors and possibly new secondary beams. We are not in a position to be specific about these developments at this time. We would expect such activities to be funded from the annual capital equipment and accelerator improvement budgets for Fermilab.

2.2 Fermilab Energy Saver (Project 79-9-b)

1. The Department's December 2, 1983 response to question 20 submitted by Chairman Fuqua on October 27, 1983 noted that the Energy Saver had met all performance specifications "with the exception that the top energy to date for circulating beam has been 700 GeV, not the 800 GeV specified as an Energy Saver objective." Has this 800 GeV specification been achieved?

Answer: The Energy Saver superconducting accelerator at Fermilab achieved its design goal of accelerating a beam of circulating protons to 800 GeV on February 15, 1984. This accomplishment established a new world record for accelerated beams. The 800 GeV beam has been extracted from the accelerator and the Energy Saver/Tevatron is now an operational research facility providing beams to high energy physics experiments at 800 GeV.

2. The December 2 response also indicated that as of September 30, 1983, some $2.6 million in contingency remained and that this would be spent primarily on the refrigeration system and on several other required modifications. Is it still anticipated that these contingency funds are sufficient to complete the project, and if not, how much more is required?

Answer: The remaining Energy Saver contingency funds will be spent primarily on the helium refrigeration system and on modifications to increase the superconducting accelerator's operating reliability and beam intensity. Of the $2.6 million which was available at the start of the fiscal year, $1.0 million has been committed and the remainder will be committed by the end of the fiscal year. These funds are sufficient to fully complete the construction project, and no further funding requests for the Energy Saver are anticipated.

3. Is formal closeout for the project still anticipated by September 30, 1984?

Answer: Formal closeout of the Energy Saver construction project is still anticipated by September 30, 1984.

2.3 Tevatron I (Project No. 81-E-218)

1. **What new types of physics will be explored by the Tevatron I?**

   Answer: Due to the unprecedented 2 TeV reaction energy capability of the Tevatron I facility, it opens up a completely new domain for investigation. Its research program will be highly exploratory. The expectation is high that totally new and unexpected subnuclear phenomenon may be discovered. Furthermore, there are currently several credible theories which predict phenomena that cannot be tested with any existing high energy physics facility, but which can be investigated by experiments at Tevatron I. An outstanding example is whether the anticipated sixth quark exists or not. If it is not found at Tevatron I energies, profound revisions to our current understanding of the strong nuclear forces will become essential. Another example is whether the known quarks are the fundamental building blocks of matter, or might themselves have constituent structure. This possibility can be rigorously tested at Tevatron I energies. Recent preliminary indications from the CERN proton-antiproton collider suggest that there may be important, unanticipated phenomena in the 150 GeV mass range. The Tevatron I energy is ideal to explore this mass range in detail and to discover whether there are related phenomena at yet higher energies.

2. **Will the Tevatron I be truly unique when operational?**

   Answer: Tevatron I will be a worldwide unique facility for many years after it comes into operation Once operational, it will make available a controlled reaction energy of about 2 TeV which will be the highest ever achieved. The USSR is building a new proton accelerator facility (UNK) at Serpukhov which is scheduled to come into operation in the early 1990's with an energy of 400 GeV x 3000 GeV, putting it in a similar range of interaction energy as Tevatron I. The Superconducting Super Collider being considered in the U.S., a possible hadron collider in the LEP tunnel at CERN, and a later phase of UNK would provide much higher energies, but these could not come into operation until the mid-1990's.

3. **How will Tevatron I's expected performance compare with any other hadron collider in the world that are operating, under construction, or planned? When is another hadron collider competitive to the Tevatron I expected to be available?**

   Answer: One other hadron collider, the 270 GeV x 270 GeV proton-antiproton collider which is a modification to the Super Proton Synchrotron (SPS) at CERN, is in operation now and will be operating with improved capabilities when Tevatron I becomes operational. Tevatron I is expected to have about three times higher energy and about ten times higher intensity than the European facility.

   There is a Soviet accelerator called UNK, which is under construction and which has an ultimate design goal of 6 TeV reaction energy. We do not foresee this phase of UNK becoming operational before the mid-1990's. In its initial phase, scheduled for completion in the early 1990's, UNK would have a total energy capability comparable to Tevatron I.

The U.S. high energy physics program has recently started preliminary R&D on a potential Superconducting Super Collider (SSC) project which would be roughly a 40 TeV reaction energy facility This project, of course, would greatly exceed the Tevatron I energy but cannot be in operation before 1994.

There have been discussions in Europe of perhaps installing a hadron collider in the tunnel now being constructed for the Large Electron-Positron (LEP) collider at CERN near Geneva. Should this project be undertaken, it, too, would probably become operational in the mid-1990's and would be at an energy between Tevatron I and SSC.

4. **What is the construction status of the accumulator and debuncher rings?**

   Answer: The construction of the accumulator and debuncher rings is now about one-third complete. They are on schedule for initial test operations in the spring of 1985 and completion early in 1986.

5. **What is the construction status of the two experimental detector areas?**

   Answer: One of the experimental areas is completed and is being used for the assembly of the first Tevatron I major detector. Construction of the second experimental area is scheduled to start in the spring of 1985 and be completed early in 1986.

6. **Is the Tevatron I still within the October 1983 estimated construction budget of $82.5 million? If so, is the $13.8 million in contingency still available, and if not, what explanation is there for additional cost overruns?**

   Answer: The total estimated construction cost of Tevatron I remains at $82.5 million. More than half of that sum has already been obligated, and the remaining contingency of about $7 million is considered adequate for project completion. Therefore, no overrun of the Tevatron I construction budget is anticipated.

7. **Is the project still on schedule?**

   Answer: The Tevatron I project is still on schedule for completion by the end of FY 1986.

8. **Are the direct R&D operating costs still within the $43.4 million estimated? If not, please explain the reasons for any variances.**

   Answer: The R&D operating costs in support of the Tevatron I project are now estimated to total $44.9 million, which is about three percent higher than the earlier estimate. This increase is spread among numerous technical components and reflects minor difficulties in developing designs and prototypes of the magnets for the debuncher and accumulator rings and of beam cooling devices which employ very advanced technology. No significant further increases in R&D costs are anticipated, and the R&D phase of the project will be essentially complete by the end of FY 1985.

2.4 Tevatron II (Project No. 82-E-206)

1. **What new types of physics will be explored by the Tevatron II?**

   Answer: Since Tevatron II is an upgrade and enhancement of the Fermilab fixed-target experimental research facilities, the research with these facilities will extend the scientific opportunities described earlier in response to question 2.1.1 regarding the fixed-target program.

   The higher energies which become available to research with Tevatron II yield two benefits: the reaction energies of the experiments are significantly increased from those available elsewhere in the world, and the intensities of the Fermilab secondary beams become much higher. The increases in reaction energies will make possible the creation and study of more massive new elementary particles. The intensity increases will make the rate of particle interactions much higher so that more data can be collected than before in a given period of time and permit the study of rare processes and particles with greater statistical precision.

   Furthermore, two of the new secondary beam lines provided by the Tevatron II project will open unique new research opportunities. The polarized proton beam will allow the study of how the spin orientation of particles affects the way in which they interact, at almost ten times higher reaction energies than before. The prompt neutrino beam has as its primary purpose the search for the tau neutrino. This particle is firmly predicted to exist on the basis of current knowledge, but has not yet been detected because that requires both energies and intensities not previously available. Should the tau neutrino be discovered with Tevatron II, many of its properties can be studied to determine if it behaves as predicted. If it is not found, a profound revision of our currently successful quark model of subnuclear matter will have to be made.

2. **Will Tevatron II be truly unique when operational?**

   Answer: The Tevatron II capabilities for high energy fixed-target experiments are expected to be unique in the world for years to come. There is no other fixed-target research facility with such high energies and beam intensities for the near future. The only other known high energy facility planned to have fixed-target capability is the 3 TeV UNK accelerator under construction in the USSR, which is scheduled to come into operation in the early 1990's.

3. **How will the Tevatron II's expected performance compare with any other fixed-target hadron accelerators in the world that are operating, under construction., or planned? When is another device competitive to Tevatron II expected to be available?**

   Answer: The design performance of Tevatron II, parts of which are already operating at 800 GeV, is to provide more than twice the energy and secondary beam intensity as that of the Super Proton Synchrotron at CERN which had been the highest energy fixed-target high energy physics facility in operation after shutdown of the Fermilab 450 GeV main ring to install the Energy Saver. The Soviet UNK facility will provide higher energy fixed-target capabilities when it comes into operation in the 1990's.

4. **What progress has been made in upgrading the external beam switchyard to 1 TeV?**

Answer: The upgrade of the extraction system and external beam switchyard to a 1 TeV capability was completed and made operational last October. It is now possible to deliver 1000 GeV protons to the primary beam target stations in all experimental areas.

5. **What is the status of the 1 TeV target assembly and experimental stations?**

Answer: About half of the Tevatron II target stations are now operational. The remainder are in various stages of construction and are on schedule. The completion of target stations is being phased with the schedule for major beam line and experimental hall construction. The wide band photon beam procurements have recently begun and conventional construction is about to begin, with completion expected early in FY 1985; muon beam procurements are more than half complete and the conventional facilities are partially under contract, with completion scheduled for late FY 1985; the prompt neutrino facility procurements are about half complete, conventional construction is essentially complete, and operation is scheduled to begin in FY 1985; the polarized proton beam and meson west pion beam upgrades are still in the design stages, with completion not expected before late FY 1985.

6. **What is the status of the new secondary beamlines (and beam line replacements) in the external experimental areas? What percentage of the equipment has been completed and what progress has been made on the support facilities?**

Answer: The enclosures and support facilities for the upgraded and new secondary beam lines in the Fermilab external experimental areas, which are being provided under the Tevatron II project, are on schedule and in various stages of construction. The new experimental halls are in the same status, and the storage and materials handling capabilities are almost complete.

The secondary beam components to be installed in the beam line enclosures and the detectors for the approved experiments are funded from the capital equipment budget. Procurement of this equipment is about 40 percent complete. The stiff competition for capital equipment funds in the national high energy physics program will delay full completion of some of the new secondary beam lines beyond FY 1985.

7. **Will Tevatron II construction be completed within the July 1983 estimate of $49.0 million? If not, please explain the reasons for any expected schedule and/or cost overruns.**

Answer: We are confident that the Tevatron II construction project will be completed on schedule by the end of FY 1985 and within its original cost estimate of $49.0 million.

8. **If the project is still within budget, how much of the $3.5 million contingency remains uncommitted? How much of the other project-related costs and direct R&D of the estimated $18.0 million remains uncommitted?**

Answer: About $1.8 million of the project contingency remains uncommitted, and about 60 percent of the construction funds have now been obligated. The current contingency is considered to be adequate. Of the other project funding originally estimated at $18.0 million, $6.8 million remains uncommitted.

3.0 Stanford Linear Accelerator Center (SLAC)

1. **What have been SLAC's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: Two preliminary remarks are in order. First, the experimental work that is described below was carried out at SLAC by physicists from many different universities and other institutions throughout the United States and from other nations, as well as by those from Stanford University and SLAC itself. The work is truly national and international in scope, with participants from about 50 U.S. institutions and about 20 foreign institutions. About 75 percent of the participants in the experimental program are from institutions other than Stanford and SLAC.

Second, it will be helpful in understanding the following descriptions to realize that elementary-particle-physics research has reached a stage where the basic concepts can be described in terms of a model of considerable simplicity. The aim of this research is to observe and understand the most basic constituents of matter, and also to understand the fundamental forces that act upon them. At present, all of the basic constituents of matter can be grouped into three families of particles: (1) the leptons, which include the electron as the best-known member; (2) the quarks, which stick together in groups of three quarks, or one quark and one antiquark, to make up particles such as the proton, the neutron, and the pi mesons, as well as many other members of a large class of nonelementary particles called "hadrons", and (3) the force-carrying particles, which include the photon as the carrier of the electromagnetic force.

The present picture of the fundamental forces in nature also can be described in a model of considerable simplicity in the sense that there appear to be only four such forces: (1) gravitation, which is very important in the large-scale world of our senses but so far has had little bearing on our search for the elementary particles; (2) electromagnetic forces, which bind the particles in atoms; (3) the weak force, responsible for some forms of radioactivity; and (4) the strong force, which binds together the quarks in nuclei. During the past ten years it has been learned that the weak and electromagnetic forces have a common origin, and in this sense that they are a single unified "electroweak" force. The theory that provides the most accurate description of the strong force, called QCD, may eventually be unified with the electroweak theory in a single, coherent mathematical structure. This kind of unification of seemingly diverse phenomena is of great importance in achieving better understanding of the nature of matter at the fundamental level.

Research at SLAC is concentrated on measuring the properties and behavior of the basic particles, and the ways in which the particles interact with one another through the fundamental forces.

Experimental Research at SLAC

The following examples illustrate some of the more important experimental results that have been obtained at SLAC since 1981.

1. Charmed Particle Lifetime

Five kinds of quarks are presently known. The fourth of these is called the "charmed" quark. The combination of a charmed quark with a different kind of antiquark (or vice versa) produces a particle called a charmed meson. Measuring how long this meson exists before it decays into other particles provides an indirect measurement of the lifetime of its constituent charmed quark to change to a strange quark. The measured lifetime of the charmed meson is less than a millionth of a millionth of a second, and the measurement of so short a lifetime required the use of two exceptionally clever techniques. In the first measurement, a special device called a vertex detector was used to allow a distinction to be made between the point at which the new particle was created and the point at which it decayed. This distance is only about 100 micrometers (a few times the thickness of a human hair), but a sampling of many different events of this kind made it possible to infer the average decay distance, and thus to calculate the lifetime of the particle. A second measurement of the charmed meson lifetime was made in a specially adapted bubble chamber, where the particles were created in the chamber by a monochromatic beam of high energy gamma rays produced by back scattering of a laser beam from an electron beam from the SLAC two mile linear electron accelerator. This experiment made use of a special camera added to the bubble chamber that was able to resolve particle tracks with a resolution of 55 micrometers, and was thus actually able to photograph the track of the charmed particle before it decayed.

2. The EMC Effect

Some time ago the European Muon Collaboration (EMC), a group working at the CERN lab in Geneva, reported a result that has stimulated both a review of old work and some new experimental work at SLAC. Briefly, the two groups agree that beams of electrons (SLAC) or of the "heavy electrons" called muons (CERN) used in scattering experiments produce results that depend upon the kind of target that is used. For example, the nucleus of a deuterium atom contains two nucleons (one proton plus one neutron), while the nucleus of an iron atom contains fifty-six nucleons, and the assumption was that the electrons or muons would scatter off the quarks that constitute these nucleons in a manner that did not depend upon how many nucleons were grouped together within a nucleus. But this turned out not to be the case. For the heavier nuclei, there seem to be more quarks that have low momentum, and fewer quarks that have high momentum. One of the possible explanations of this result is that quarks may not be bound as tightly and as permanently within the confines of a single nucleon as had been thought, but may wander between individual nucleons. It also may be that larger "bags" of quarks are possible than the usual three to a bag.

3. "Charmonium" Spectrum

Physicists are particularly interested in simple systems of particles that can exist in many different energy states. An example is the hydrogen atom, which consists of one electron and one proton bound together by the force of electromagnetism, and which can exist in many different "excited" states. An even simpler example is the "atom" called "positronium", which consists of an electron bound together with its antimatter counterpart, a positron. The whole series of states in which such combinations can exist is called its spectrum, and the study of such states is called spectroscopy.

The combination of a charmed quark and a charmed antiquark is a similar system called "charmonium", and studies of charmonium spectroscopy have been important at SLAC ever since the original discovery of this system in 1974. In recent years a special detection system designed to detect energetic photons (the Crystal Ball) made a detailed study of all the states of charmonium that could be reached by having a higher energy state emit a photon and drop down to a lower energy state. This led to the discoveries of two important states (eta-c and eta-prime-c) that confirmed the spectrum and its similarity to the analogous spectrum of positronium.

4. Particles that may Consist of Gluons

The strong force that binds quarks together inside hadrons is believed to be carried by particles called gluons. According to the well-regarded theory that describes this force (quantum chromodynamics, or QCD), it should be possible for two or more gluons themselves to stick together to form discrete particles. Both the Crystal Ball and the Mark III detectors working at SPEAR have uncovered evidence for states that are candidates for "glueballs". The Mark III is continuing the study of these and other states that are observed when the psi particles (charmed quark-antiquark combinations) decay into other particles by emitting a photon. One new state that has been discovered in this work does not yet have a satisfactory explanation in terms of known phenomena.

5. Bottom Quark Lifetime

The lifetime of the fifth or bottom (b) quark to change to a charmed quark has been measured in two different sets of experiments carried out at the PEP storage ring at SLAC. The first measurement was made with the MAC detector, and this was soon followed by a similar measurement made with the Mark II detector. The measurements are in general agreement, with the value of the lifetime being set at slightly longer than a millionth of a millionth of a second. Although short by ordinary standards, this lifetime is quite long in the natural time scale of the particles. In addition, because of interrelationships among the different kinds of quarks (they appear to come in pairs, with each pair forming a different "generation"), this work implies the existence of a sixth kind of quark, already named "top", but not yet discovered. The lifetime of the b quark is also an indirect indication of the mass of the predicted t quark, and is thus a guide in the search for t quark.

6. Tau Lepton Lifetime

The MAC and Mark II groups working at PEP have also been able to measure the lifetime of an elementary particle called the tau, which was discovered at SLAC in 1975, and which is an even heavier relative of the electron and its heavier brother, the muon. The sequence of electron, muon, tau has a mass relationship of roughly 1:200:4000, but in all other respects these three particles appear to behave in exactly similar ways. That there should be three such generations of electron-like particles is one of the most intriguing, and unexplained, aspects of research in this field. The two measurements recently performed at PEP agree on a tau lifetime of about three tenths of a millionth of a millionth of a second - a value that is consistent with the idea that the electron, muon and tau differ from each other only in their masses.

7. Electroweak Force Studies

Our present understanding of the electromagnetic and weak forces results in the prediction that the process by which electron-positron collisions in the PEP machine lead to the creation of a pair of muons should occur in an asymmetric manner. This is an important test of our ideas of electroweak unification, and the required experiments are now being carried out by several of the groups working at the PEP machine. Enough evidence is now available to provide general confirmation of the theory's prediction. The measurements made at PEP will be compared with the similar measurements made at somewhat higher energies at the German PETRA ring to determine how the observed asymmetry depends upon the energy of the initial collision.

8. Tests of QCD

In a more general vein, all of the experiments now in progress at the PEP storage ring are collecting important information about how the initial process of electron-positron annihilation leads to the production of strongly interacting particles (hadrons), and of how the quark composition of these particles changes as they subsequently decay to lighter particles. These are the processes that the promising theory of the strong interactions, QCD, purports to describe, and they are thus tests of the theory. Definitive testing of QCD is still some distance away from us, both because the theory itself does not in general presently lend itself to precise prediction, and also because some of the proposed experimental tests will require higher energies or a degree of precision that are presently unattainable.

9. Search for Unusual Particles

There is a very attractive but speculative theory called "supersymmetry" (SUSY) that can in principle incorporate the force of gravity within the framework of elementary particle theory. One of the predictions of this theory is that there should exist supersymmetric "partners" of the ordinary particles which differ from them only in a certain property (spin) and probably in mass. The MAC detector at PEP has already carried out a search for two of the predicted kinds of supersymmetric particles ("selectron" and "photino"), and in fact at present has one potential candidate for a photino. It is much too early to get excited about this one event, but the subject itself is very important. In fact, a separate dedicated experiment to search for SUSY particles is now being set up in one of the research areas at PEP for operation next year.

2. What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?

Answer: The facility changes and additions at SLAC over the specified period are described in the two sections which follow:

A. Buildings

Project	Square Feet	Amount	Starting Date	Comments
MCC	5,400	$554,000	01/22/82	Additional accelerator control room space

Project	Square Feet	Amount	Starting Date	Comments
Test Lab Addition	5,000	706,000	12/23/81	Double existing space for fabrication of klystron amplifier tubes.
Electronics Building Annex	22,500	995,000	07/22/83	Additional on-site office and light laboratory space.
Warehouse	20,000	800,000	01/13/84	Initially SLC magnet receiving assembly, testing in support of SLC project. When SLC complete, conversion to warehouse and salvage function.
Central Lab "Notch" Fill-In	4,600	400,000	*	Additional office and light laboratory space.
Central Lab 3rd Floor Modification	13,440	950,000	*	Additional office and light laboratory space.

* Not started yet.

B. Accelerators

The three items included here are linac instrumentation and controls upgrade, linac energy upgrade and, of course, SLC construction. The present SLAC linac is capable of accelerating a beam of electrons to about 33 GeV. The energy upgrade is increasing this to 50 GeV. This higher energy is important for the fixed-target research program using beams from the linac. This energy of 50 GeV is also important for the SLC to produce a total collision energy of 100 GeV and thus fulfill its physics goal of producing the Z^o particle in copious quantities.

The upgrade of the instrumentation and control system of the linac is important to improve the accuracy with which beams can be monitored and controlled in the linac. For example, the beams must be injected onto the exact centerline of the linac with a margin of effort no greater than about 25 microns (about the width of a human hair) in order for the SLC to work properly. If the beams are further off center, they become distorted in a way that will prevent the achievement of a sufficiently small spot size at the collision point. This is only one example of many new stringent requirements on geometrical accuracy, on focusing, on beam monitoring and control, etc., that SLC operation will impose upon the present linac systems and components. The SLC construction project is described in detail in response to the set of questions in section 3.4.

3. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to SLAC. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: The requested data is given in the following table.

SLAC Funding
FY 1981 - FY 1985
(Budget Authority in $ Thousands)

	Source of funds	FY 1981	FY 1982	FY 1983	FY 1984 Estimate	FY 1985 Request
Operating		$55,620	$61,275	$75,298	$74,160	$81,950
In-House Research	HEP	7,450	8,800	8,030	10,500	11,100
Operations	HEP	38,770	39,002	42,700	48,400	52,900
Other Operating Exp	HEP	9,400	13,473	24,579	15,248	16,700
Med Energy Nuc Physics	NP	0	0	0	0	1,090
In-House Energy Mgmnt	IHM	0	0	18	12	0
Equipment		$ 6,650	$ 6,500	$ 6,121	$ 6,895	$10,900
Work for Others*	NSF/BES	1,552	1,670	1,445	2,216	2,233
Construction		$ 2,950	$ 3,767	$ 5,531	$35,200	$64,700
GPP	HEP	1,000	1,260	1,040	1,300	1,500
AIP	HEP	1,200	1,600	2,000	1,900	2,700
PEP Claims	HEP	0	0	2,176	0	0
PE&D (SLC)	HEP	750	908	315	0	0
SLC	HEP	0	0	0	32,000	60,500
Total*		$66,772	$73,212	$88,395	$118,471	$159,783

* Includes one-half of SPEAR funding to cover duplicated operation for SSRL. These funds were provided by NSF in FY 1981 and 1982 and by the DOE Basic Energy Sciences Program in FY 1983 through 1985.

4. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

Answer: The Stanford Linear Accelerator Center receives no funding directly from any other Federal agency or from any state agency for high energy physics research. SLAC did receive reimbursement from NSF in FY 1981 and FY 1982 for incremental costs associated with dedicated operation of the SPEAR colliding beam ring to provide beam for research conducted at the Stanford Synchrotron Radiation Laboratory. The NSF reimbursement amounted to $3,222,000.

5. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

Answer: SLAC Staffing levels are as follows:

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Full Time Equivalents (monthly avg.)	1,311	1,217	1,315	1,400	1,475

6. **What is the actual and estimated facility utilization for the period FY 198 - FY 1985? What would be defined as "full" utilization of the facility?**

Answer: The following table shows accelerator utilization defined in two ways:

1. Full-shift utilization is defined as 830 eight-hour shifts/year.
2. Full-pulse utilization is defined as 830 eight-hour shifts/year at a pulse repetition rate of 360 pulses/second.

Shift utilization is the important parameter for storage rings, bubble chambers, and test beams which need only low pulse rates. Pulse utilization is the important parameter for fixed-target electron and hadron scattering where the data rate is limited by the total number of pulses delivered on target.

Accelerator Utilization

Fiscal Year	Shift Utilization (%)	Pulse Utilization (%)
1981	85	25
1982	83	20
1983	93	27
1984 (est.)	69	15
1985 (est.)*	70	18

* Does not include planned nuclear physics run during summer downtime--180 shifts @ 180 pulses/sec using 1/5 of the linac accelerator.

7. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer: The research program at SLAC has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment." This approved detector is used by the investigators to log a large class of events under a variety of operating conditions. The table below gives the numbers of such detector installations started, continued, and completed, in the period FY 1981 - FY 1985.

SLAC Detector Installations Started, Running, and Completed by Year for FY 1981 - FY 1985, Inclusive

	Fixed-Target	SPEAR	PEP
FY 1981			
Started	0	0	1
Running	3	1	6
Completed	0	0	0
FY 1982			
Started	1	2	1
Running	4	3	7
Completed	6	2	0
FY 1983			
Started	2	0	0
Running	5	1	7
Completed	6	0	1
FY 1984			
Started	0	0	0
Running	2	1	4*
Completed	6	0	0
FY 1985 (est)			
Started	1	0	1
Running	1	1	7
Completed	0	0	0

* In FY 1984 only, PEP-4 and PEP-9 were off, to allow installation of a superconducting magnet for the TPC detector facility.

The use of one detector facility for a large number of separate experiments, each leading to a number of publications, may be illustrated by the case of the SLAC-LBL group which carried out the research program with the Mark I detector at the SPEAR storage ring at SLAC during the period from 1972 through 1976, producing a total of forty-three publications based on that work. This compares with the more typical one or several papers that result from a typical fixed-target experiment at a proton accelerator.

8. **What is SLAC's user policy?**

Answer: SLAC's facilities are available to qualified physicists whose research proposals are judged, after thorough review by the SLAC Experimental Physics Advisory Committee and the Laboratory management, to be of sufficiently high scientific promise and compatible with SLAC's capabilities and resources. Beam time is provided free of charge to the users for approved high energy physics experiments. For each approved experiment, an understanding is reached at the time of scheduling, by the Laboratory and participants in the experiment, specifying the responsibilities, commitments, and contributions of all parties. Users for purposes other than high energy experiments will be charged either incremental or full costs depending on the nature of the research of the performing institution.

9. For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?

Answer: Stanford Linear Accelerator Center has historically not done any reimbursable high energy physics research nor does it contemplate doing any in the future. The laboratory does however operate the SPEAR colliding beam ring one-half time to provide beam for the research conducted at the Stanford Synchrotron Radiation Laboratory for which it receives reimbursement for associated incremental expenses. A total of $9,116,000 of reimbursement has been received, as indicated in response to question 3.0.3.

10. What is the mechanism by which specific research proposals for experiments at SLAC are considered?

Answer: The Experimental Program Advisory Committee (EPAC) advises the Director of the Stanford Linear Accelerator Center (SLAC) on the selection of facilities and experiments for the Linear Accelerator (Linac), the Stanford Positron Electron Asymmetric Ring (SPEAR) and the Positron Electron Project (PEP) programs, and on modifications of facilities and basic installations which would substantially influence the experimental program. On matters concerning PEP, the EPAC also advises the Director of the Lawrence Berkeley Laboratory (LBL) because PEP was a joint SLAC-LBL construction project.

The members of the EPAC are appointed jointly by the Directors of LBL and SLAC after broad consultation within the high energy physics community, including the SLAC/LBL User's Organization and with the concurrence of DOE. The EPAC has twelve members, drawn from the physics community as follows:

(1) At least three of the twelve members are selected from at least six nominees of the SLAC/LBL User's Organization, and

(2) At least seven of the twelve members are high energy physicists not employed by Stanford University (including SLAC), LBL or the University of California at Berkeley.

The EPAC elects its own chairman. In order to preserve continuity, the original appointments had different durations with approximately proportional number of members from each group referred to above, having terms of two and three years. All subsequent appointments have a 2 year term.

Proposals for experiments requiring approval are referred to the SLAC Program Coordinator who presents them to EPAC at their next meeting. The Program Coordinator also presents to the EPAC information regarding the availability and suitability of the Laboratory's resources for carrying out any particular proposal, as well as relevant information regarding the interaction of the various proposed programs. Proposals need to be spelled out in sufficient detail to provide a reasonable basis for a decision. The proposals, in particular, give a quantitative justification for the requested amount of setup, testing, and running time as well as estimates of the SLAC services and equipment that will be required. The experimenters are entitled to give an oral presentation to the Committee should they so request, and may be asked by the EPAC to do so. Only proposals for specific experiments or tests will be considered. There will not be allocations of "blocks" of time for unspecified use.

Proposals may request the use of a major facility (such as a large spectrometer) for a specific experiment. Such proposals for facility time are treated on the same basis as requests for beam time.

In making a judgment on the suitability of any particular proposal at a particular time, the Director and the EPAC consider, among other factors: (a) the scientific merit of the proposed experiment; (b) the compatibility of the proposed experiment with other experiments which might be accommodated in the same time period; (c) the availability of service manpower (such as engineers, alignment technicians, and rigging crews); (d) the availability of magnets, electrical power, and special equipment; (e) the requirement for accelerator downtime or any other interactions with the total experimental program; (f) the possible complementary features of experiments that would make it desirable to accommodate them together on the schedule (so as, for example, to provide flexibility and backup for the day-to-day scheduling); and (g) the limitations imposed by the SLAC operating budget. The competence of a particular group to accomplish a proposed experiment is also taken into account in the deliberations.

Every experiment which is accepted in the program is required to meet SLAC safety requirements before it can be installed in the experimental areas.

11. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

Answer: As discussed in response to question 3.0.7, the research program at SLAC has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment." This approved detector is used by the investigators to log a large class of events under a variety of operating conditions. The numbers of research proposals submitted to Stanford Linear Accelerator Center Center and those approved by calendar year 1979 -1983 are shown in the following table:

	1979		1980		1981		1982		1983	
	SUB	APP	SUB	APP	SUB	APP	SUB	APP	SUB	APP
Fixed Target (Includes HBC)	6	4	2	1	0	1[*]	0	1	1	1
SPEAR	1	1	1	1	1	1	0	0	0	0
PEP	1	1	0	0	0	0	0	0	1	1
SLC	--	--	--	--	--	--	9[**]	0	1	1[***]

[*] E-136 approved in 1981, was submitted in 1980.

[**] 9 Letters of intent were received; these were treated as proposals.

[***] The MKII Letter of intent was resubmitted in final proposal form, and approved in 1983.

12. **How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?**

Answer: During the past five years, the number of users from U.S. universities (including non-SLAC Stanford personnel) who have participated in the Stanford Linear Accelerator Center experimental program is about 520, of whom about 120 were graduate students.

13. **How many industrial researchers have utilized the facility over the past five years?**

    Answer: There have been no industrial researchers who have used Stanford Linear Accelerator Center's high energy physics experimental facilities, during the past five years. However, there are industrial users of the SSRL facility, which is not part of the high energy physics program, but which does receive beam from the SLAC accelerators.

14. **How many researchers from foreign institutions have utilized the facility over the past five years?**

    Answer: During the past five years, the number of foreign experimental physicists who have participated in the Stanford Linear Accelerator Center experimental program is about 125, of whom about 22 were graduate students.

15. **How many researchers from other agencies have utilized the facility over the past five years?**

    Answer: No researchers employed by other agencies have utilized SLAC's high energy physics facility during the past five years. However, approximately 130 university researchers who receive their direct research support through NSF grants have utilized the facility during that period.

16. **What are the future development possibilities for SLAC (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

    Answer: The major development underway is, of course, the Stanford Linear Collider (SLC) presently under construction at a total estimated cost of $112 million) and scheduled for initial operation in early 1987. Two detectors are planned—an upgraded Mark II detector and a new detector specifically designed for SLC physics (called SLD). In addition to providing new opportunities for research, the SLC project is expected to explore the feasibility of single pass, electron-positron collisions with linear accelerators. At present, exploitation of such linear colliders is seen as the only way to achieve energies much higher than the 150 GeV which will be reached with CERN's LEP, the highest energy circular collider for electrons and positrons. The future SLAC and U.S. program will depend on how high energy physics research progresses, the ingenuity of the SLAC researchers in physics and in accelerator R&D and the availability of funds.

17. **Please provide a copy of SLAC latest annual report.**

    Answer: The Stanford Linear Accelerator Center (SLAC) does not issue annual reports. Attached are copies of some recent SLAC monthly operations status reports.

STANFORD LINEAR ACCELERATOR CENTER
MONTHLY REPORT FOR DECEMBER 1983
I. ACCELERATOR AND RESEARCH OPERATIONS

A. OPERATING HOURS (Manned Hours)

Physics Beam Hours:[1] (Machine and Particle Physics) .... Total 499

Non-Physics Hours: Scheduled Downtime 8, Unscheduled Downtime 21. Total 29

TOTAL OPERATING HOURS 528

B. ELECTRON PULSES GENERATED

Total 1.1×10^8 Average 60 PPS

C. EXPERIMENTAL HOURS[2]

1. Particle Physics

EXPERIMENTAL AREA OR BEAMLINE[3]	EXPERIMENTAL TIME (Actual Hours)	TEST AND CHECKOUT HOURS	TOTAL EXPERIMENT HOURS
PEP			
IR- 2			
IR- 4	352		352
IR- 6	352		352
IR- 8	352		352
IR-10			
IR-12	352		352
SPEAR			
EAST PIT			
WEST PIT			
ESA 3		8	8
ESB 19		129	129
20/21		113	113
14			
8			
ESC 27	330		330
26/6			
TOTAL	1738	250	1988

2. Machine Physics

PEP 0, SPEAR 69, LINAC 256. 325

3. SSRL (Dedicated Time at SPEAR)[4] 467

TOTAL EXPERIMENTAL HOURS 2780

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[1] Number of hours accelerator is run with one or more beams excluding accelerator beam tune-up and other non-physics beam time.

[2] Number of hours an experiment is run including actual beam hours and beam downtime "normal to the experiment."

[3] Refer to Figures 1 and 2 for beamline locations and experimental areas.

[4] Accelerator beam available to SPEAR storage ring.

D. OVERALL EXPERIMENTAL PROGRAM STATUS

1. Electronic Experiments

	Factored Hours*
Approved research hours at beginning of month	256
Hours run during the month	—
New hours approved during the month	—
Approved hours remaining at end of month:	256

2. PEP and SPEAR Experiments

	Actual Hours PEP	Actual Hours SPEAR
Approved research hours at beginning of month		2127
Hours run during the month	1408	—
New hours approved during the month	—	—
Approved hours remaining at end of month:	—	2127

3. Bubble Chamber Experiments

	40" BC Hours	40" BC Pictures
Approved research hours at beginning of month	2267	1024 K
Hours run during the month	330	257 K
New hours approved during the month	—	—
Approved hours remaining at end of month:	1937	767 K

E. BEAM INTENSITY

Peak	140 mA
Average	17.14 μA

F. KLYSTRON EXPERIENCE

Total Klystron Hours	125,083
Number of Klystron Failures	2

G. DATA ANALYSIS

Bubble Chamber Events Measured	247

H. COMPUTER OPERATIONS (Manned Hours)

COMPUTER OPERATIONS (Manned Hours)	3081
Computation Hours	
SLAC Facility Group	2
User Groups	740
Total Computation Hours:	742
Non-Computation Hours	
Scheduled Maintenance	—
Scheduled Modifications	—
Unscheduled Downtime and Reruns	1
Idle Time	—
Utility Failure	—
Misc. Failure	1
Total Non-Computation Hours:	2
TOTAL MANNED HOURS:	744

I. SPECIAL OPERATION FEATURES

The accelerator was operated for 65 shifts at 60 pps in December. A total of twelve shifts of semi-dedicated runs for the SLAC Linear Collider were run during operations in December.

The accelerator was turned off from 2200 hours, December 22, to 0000 hours, January 3, for the Christmas and New Year Holidays.

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* Factored hours are represented by the formula $T_c = T_o(R+20)/200$ where T_c = charged hours, T_o = total hours beam was available to the experimenter for both check-out and data taking, and R = the average pulse repetition rate. Maximum for $(R+20)/200$ is 1.5 even if the calculated amount exceeds this value.

2. RESEARCH AREA AND EXPERIMENT STATUS

A. General

The accelerator operated until December 23 at 60 pps in the SLED mode and was turned off for a scheduled ten-day shutdown. PEP delivered about eleven inverse picobarns to MAC, HRS, DELCO and MARK II. During the short shutdown a new vacuum pipe and masking and several detector components were installed in IR–10 for PEP–21 (Anomalous Photon Search). In IR–2 a new nine-meter mask was installed for Two Gamma to test a BGO detector for tagging very small angle (4–10 mrad) electron-positron scattering. SPEAR operated entirely for SSRL.

In End Station C Experiment BC–75 (Charm Study in the SLAC Hybrid Facility) concluded a very successful run at the 40" Bubble Chamber. The bubble chamber was then given a retirement party for a long and distinguished career. The ten-day run in November at 10.5 GeV photon energy for BC–76 (Threshold Enhancement in Associated Charm Meson-Charmed Baryon Production) turned up no charmed lambda events, so data-taking for that experiment is concluded. (L. Keller)

B. Program Status and Reports of Experiments & Tests

Figure 1 is a research area plan showing the location of experiments and facilities. Figure 2 shows locations of the experimental beam lines in the research area. Figure 3 shows the long-range schedule. Table I is a list of presently approved high-energy experiments. The right-hand column of Table I gives the status and activity of each experiment during the cycle.

BC–75 — *Charm Photoproduction at 20 GeV*
(G. Kalmus, Rutherford Lab., and K. Moffeit, SLAC)

BC–75 finished data taking December 22 with 645,000 pictures obtained between October and December 1983. Work is in progress on the analysis of this data and that taken in the spring. A collaboration workshop was held at SLAC December 12-16 to scrutinize new charm event candidates. (K. Moffeit)

BC–76 — *Threshold Enhancement in Charm Photoproduction - Univ. Birmingham, Imperial College (London), Rutherford Lab., U.C. Berkeley, Univ. of Tennessee, SLAC, MIT*
(B. Franek, Univ. Birmingham, J. Brau, Univ. Tennessee)

A proposal to exploit a threshold enhancement in charm photoproduction (BC–76) at the SLAC hybrid facility was approved by the EPAC on November 1, contingent upon a demonstration that the enhancement exists. To test the theoretical prediction of the enhancement, the photon beam serving the SLAC hybrid facility was converted from its normal 20 GeV operation to 10.5 GeV on November 4. This low energy beam was established by running the laser with frequency doubled (rather than quadrupled) photons and running the linac at 23.3 GeV. The component changes required for this switch over were accomplished in a few hours on November 4, but due to linac tests, productive running was only established by November 6. Between then and November 19, despite numerous interruptions for linac tests, 100,000 pictures were taken for the BC–76 test

This film was scanned by the collaboration for evidence of charm using procedures developed for BC–73 and BC–75. The film scanning was over ninty percent completed by December 12, with no evidence for charm production appearing. A paper is in preparation reporting the cross section limit demanded by this null result. (J. Brau)

D–30 — *Channeling Radiation - (C. R. Sun, SUNY-Albany)*

Repairs on the goniometer were completed toward the end of summer, 1983. It was replaced in the positron beam line and in early November when beam became available we began to systematically map out all the planes in the diamond crystal. The next item was to study the angular dependance of the channeling radiation spectrum. We took many runs with a 4 mm diameter collimator set at various distances from the straightforward position. This scan was done for both the horizontal and vertical directions. Thus a set of spectra for different angles of emission were obtained for an incident positron energy of 4 GeV. The last item on the agenda was to repeat the 10 Gev runs at the highest possible repetition rate. It was immediately before this run that the goniometer broke down once again. The problem this time has proven to be in the electronic controls and is presently being repaired. (M. Pisharody)

PEP-5 - *General Survey of Particle Production at PEP (MARK II) - SLAC, LBL, Harvard (N. Lockyer-SLAC)*

After the summer shutdown, the MARK II detector was ready for the first PEP beams delivered this cycle. Improvements to the drift chambers during the summer were successful and the time-of-flight system laser was reconditioned and operates more reliably now. With 150 pb^{-1} of integrated luminosity accumulated this far at PEP, studies of particle lifetimes using the high precision vertex detector, new particle searches and jet properties are continuing. Throughout the fall cycle the detector operated reliably and by the middle of December, 16 pb^{-1} of luminosity had been recorded. (N. Lockyer)

PEP-6 — *Magnetic Calorimeter Detector to Study Electron-Positron Collisions (MAC) - Univ. Colorado, Frascati, Univ. Houston, Northeastern Univ., SLAC/Stanford Univ., Univ. Utah, Univ. Wisconsin (R. Weinstein, Univ. Houston)*

The MAC detector performed very well throughout the cycle. During the summer access a large effort had been committed to extending the detector's small angle tagging capabilities. A lead/proportional chamber sandwich was installed to provide efficient detection down to 5° from the beam direction, plus scintillators to give additional tagging down to 2.5°. This work was successful, and the system was operational for the initial luminosity delivered by PEP. Energy thresholds for the single photon trigger were lowered after last spring's test running, and using the new tagging system we are now able to veto conventional sources of single photons with $P_\perp$ greater than 3 GeV, as demonstrated by this fall's data. Results from the spring test data, setting useful limits on the supersymmetric electron mass, have already been published.

Modifications to the dE/dx system were also made over the summer to eliminate common-mode pickup originating from the PEP beams. During the cycle this system was brought up fully and is now recording data.

The speed of the PASS 1 analysis has been improved by about a factor of two, reducing the load on the IBM system. BITNET has been installed on the IR-4 VAX; although too slow for data transfer, it serves as a useful backup to the LLA for source files and allows interactive messages to be passed between the VAX and IBM systems.

Finally, although we have been disappointed by the relatively small integrated luminosity ($\sim$ 20 pb^{-1}) delivered this cycle by PEP, we are hoping that this winter's run can deliver sufficient datato provide the payback for the efforts of the summer and fall. (R. Messner)

PEP-12 — *High Resolution Spectrometer - ANL, Indiana Univ., Univ. of Michigan, Purdue, LBL and SLAC (D. Meyer, Univ. of Michigan and M. Derrick, ANL)*

During the fall cycle the HRS has collected 9.3 inverse picobarns of data. This relatively low number is partially due to the slow start for PEP luminosity and partly to cryogenic difficulties with the magnet and its refrigerator. During the cooldown in September, several of the cooling circuits that intercept the heat conducted down the magnet coil supports became plugged. After valiant attempts by the Cryogenic Group to handle the additional heat load by refrigerator modifications were unsuccessful, the magnet was warmed to room temperature, purged of contaminants, and cooled down in about six weeks (record speed!) By this time, PEP was beginning to work reliably, though at half last spring's luminosity.

At the end of December we completed the production analysis of our 1982-83 data. Preliminary studies on D^* (both $K\pi$ and $K\pi\pi$ modes), D^*, ϕ, K^*, and Λ production, and τ's were continued from this summer on a selected subsample of that data. Jet studies were continued on the fully analyzed 1981-82 data. Preliminary work on using the Čerenkov tagging in the D and ϕ analyses was started. (S. Gray)

PEP-20 — *DELCO at PEP - CalTech, SLAC/Stanford Univ.*

(J. Kirkby, Stanford Univ.)

During the fall 1983 cycle, DELCO operated smoothly and logged 20 pb^{-1} of data. These were the first data taken after installation of new Al–Hexcell–Al laminate central vacuum chamber (of thickness 0.6% χ_0). This chamber is important both in reducing γ conversion backgrounds and in minimizing lifetime-measurement errors from multiple coulomb scattering. The detector is now well-optimized for lifetime measurements; we are achieving inner drift chamber resolutions of between 120–150 μ.

Analysis of the data is also proceeding well. We have submitted for publication the first measurements from PEP/PETRA of prompt electron production over almost the full kinematic range, $0.5 < p < 5.5$ GeV/c. We expect 1984 to be a productive year for DELCO results. (J. Kirkby)

SP-32 — *Studies of Weak Decays of D Mesons at the ψ'' Resonance - Cal. Tech., SLAC, U.C. Santa Cruz, Univ. of Illinois, Univ. of Washington (D. Hitlin, Cal Tech.)*

Experiment SP-32 attempted to begin data-taking in mid-October following the long summer shutdown. Unfortunately, for reasons not fully understood, the luminosity obtained this fall at the center-of-mass energy of the ψ'' meson (3.88 GeV) was about a factor of three lower than that obtained at the same energy last spring. After, the SPEAR operations staff tried for a couple of weeks—with little success—to understand why the luminosity was so low, SP-32 decided to cancel the remainder of its scheduled experimental time for October and November. Hopefully, the problems will have been found and fixed by January 1984, the month when SP-32 is scheduled to begin data-taking again. (D. Coward)

T-345 — *Background Measurement in End Station A*

(R. G. Arnold, American University)

The purpose of this test was to measure the background in scintillator detectors in a shielded counter cave in End Station A with a 2.3 GeV electron beam stopped in the end station in a shielded dump. A small water cooled dump was installed in a concrete hut on the beam line 80 feet downstream of the pivot. Scintillation counters in the 8 GeV/c spectrometer hut were used to measure the room background with the spectrometer at angles of 15° to 35° to the incident beam. With momentum set at 2.5 GeV a 5% radiation length Al target was placed at the pivot. Measurements were taken with the target in and out and with the spectrometer entrance slits open and closed. The results indicate that room background from the multiple scattering in the target and from the dump will be low enough to allow operation of a recoil spectrometer at 0° to the incident beam with the electron beam dumped in the end station. (R. Arnold)

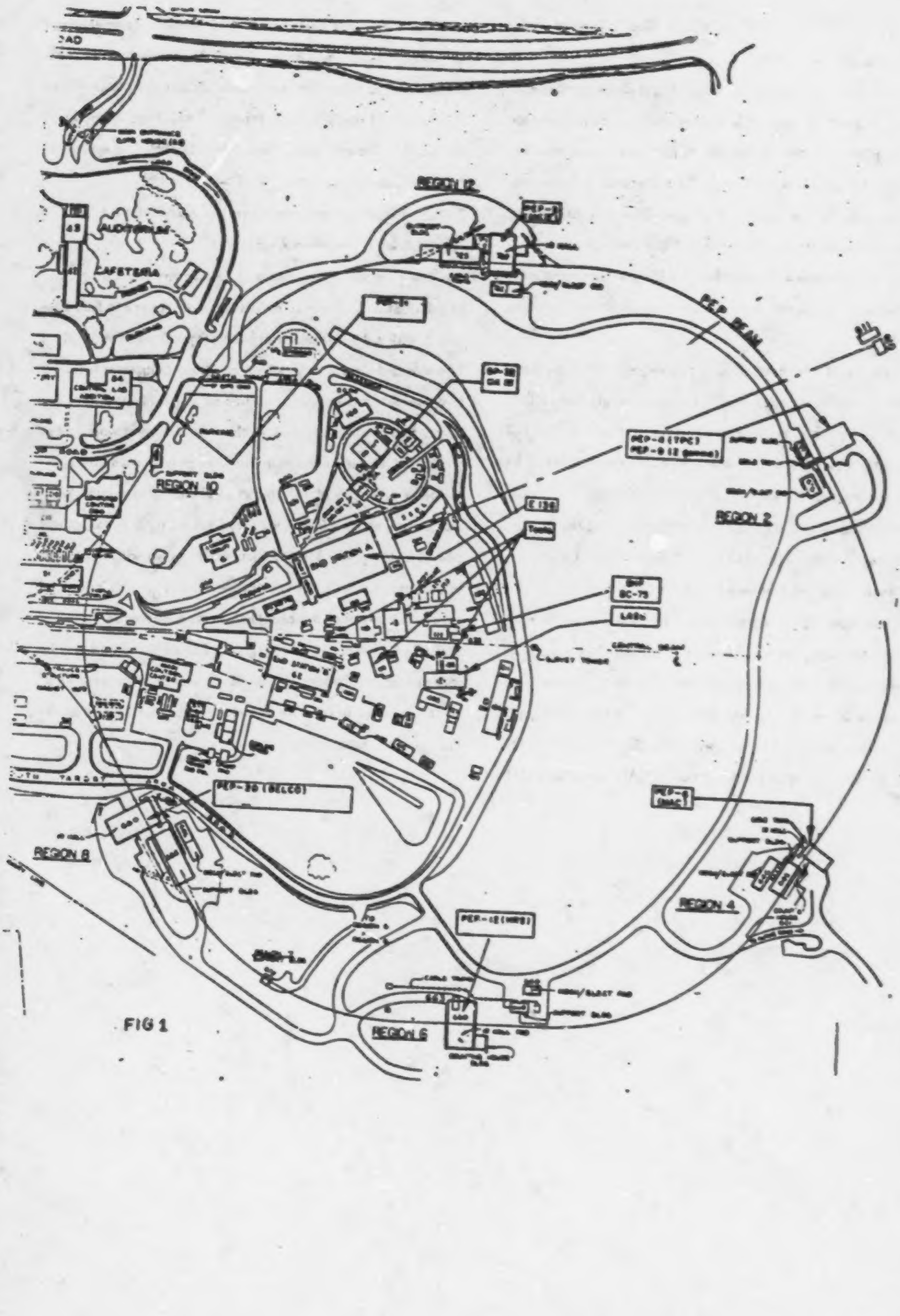
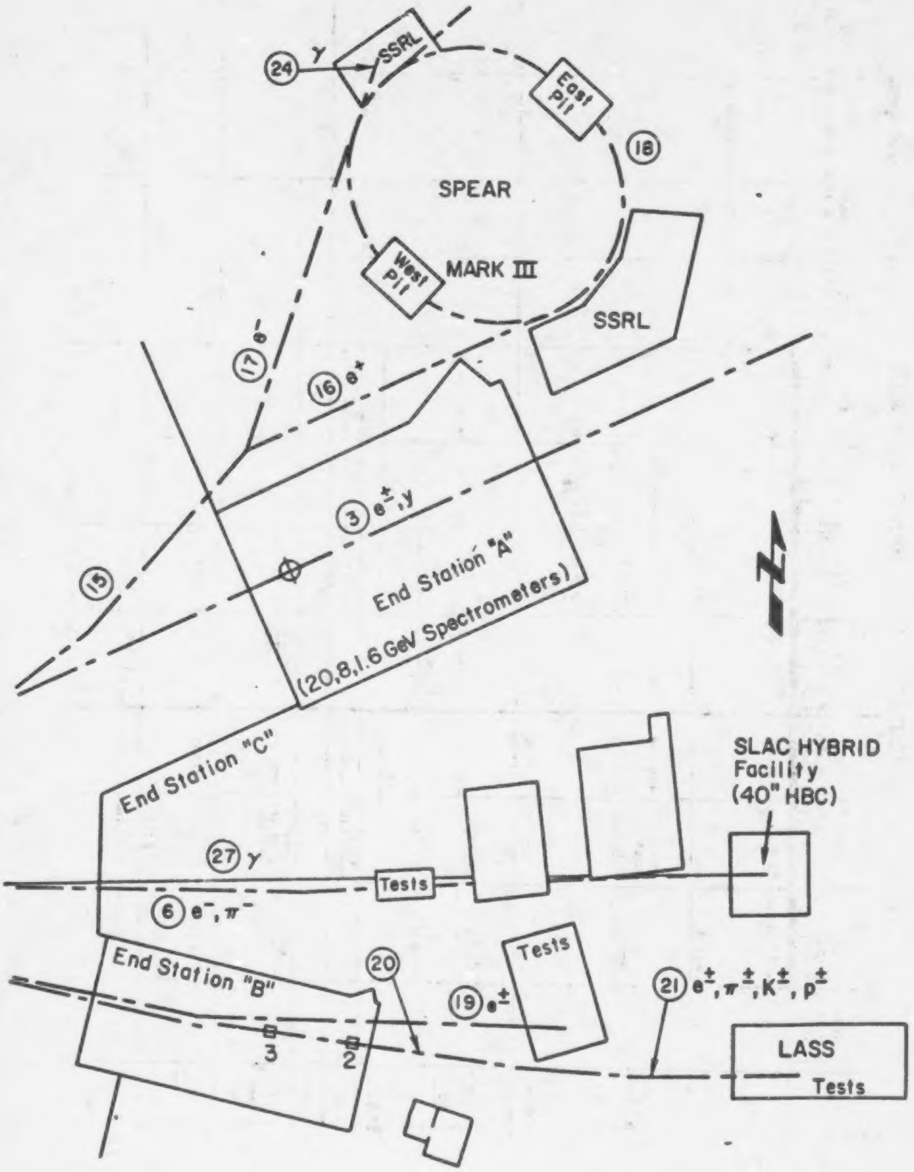

REGION 12
AUDITORIUM
CAFETERIA
CENTRAL LAB
REGION 10
END STATION A
PEP BEAM
PEP-4 (TPC)
PEP-9 (2 gamma)
E 136
BC-75
LASS
CENTRAL BEAM
REGION 2
END STATION B
PEP-20 (DELCO)
REGION 8
PEP-6 (MAC)
REGION 4
PEP-12 (HRS)
REGION 6

FIG 1



24
γ
SSRL
East Pit
18
SPEAR
West Pit
MARK III
SSRL
17 e⁻
16 e⁺
3 e±, γ
End Station "A"
(20,8,1.6 GeV Spectrometers)
15
End Station "C"
SLAC HYBRID Facility (40" HBC)
27 γ
Tests
6 e⁻, π⁻
End Station "B"
20
Tests
19 e±
21 e±, π±, K±, p±
3
2
LASS
Tests
—□— RF Separator

FIG 2

FIGURE 3

TENTATIVE LONG RANGE SCHEDULE

AF. 4 NOV 1983

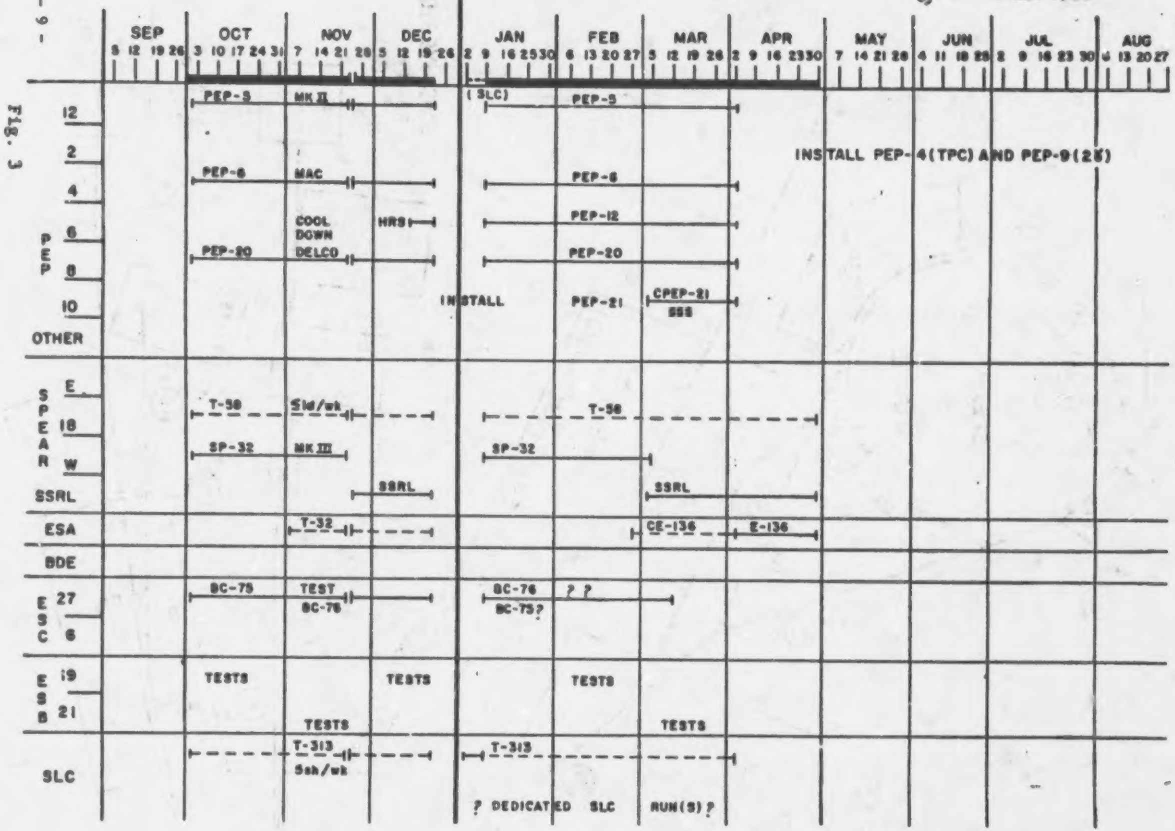


Fig. 3

STANFORD LINEAR ACCELERATOR CENTER

TABLE 1

December, 1983

TABLE OF APPROVED EXPERIMENTS

Number	Title	Experimenters	Date Approved Stage 1	Stage 2	Status
E-136	Elastic Electron-Proton Cross Sections at High Momentum Transfer	AMERICAN U.: R. ARNOLD, P.Bosted, S. Rock, Z.M. Szalata U. BONN: B. A. Mecking SLAC: D. J. Sherden	5/16/81		Inactive
BC-75	Charm Study in SLAC Hybrid Facility	RUTHERFORD LAB: G. KALMUS IMPERIAL COLL., U.BIRMINGHAM, UCB, SLAC, TOHOKU, TECHNION-ISRAEL, U.TEL-AVIV, WEIZMANN INST., M.I.T., BROWN U., ORNL, U. TENNESSEE, TUFTS U., SLAC: K.MOFFEIT	11/6/82		Running/Comp.
SP-32	Studies of the Weak Decays of D Mesons at the ψ'' Resonance	C.I.T.: R.Baltrusaitis, J.Hauser, D. HITLIN, J.Richman, J.J.Russell SLAC: K.Bunnell, D.Coward, K.Einsweiler, D.Hutchinson, R.Mozley, A.Odian, J.Roehrig, W.Toki, Y. Unno, F. Villa UCSC: H.Bledsoe, D.Dorfan, R.Fabrizio, F.Grancagnolo, R.Hamilton, C.Heusch, T.Schalk, H.Sadrozinski, A. Seiden, D. Smith U. ILLINOIS: J.Becker, R.Cassell, H.Cui, B.Eisenstein, G.Gladding, S.Plaetzer, A.Spadafora, J.Thaler, A.Wattenberg, W.Wisniewski U. WASH.: J.Brown, T.Burnett, V.Cook, C.delPapa, H.Lubatti, K.Moriyasu, J.Rothberg, J.Sleeman, H. Willutski, D. Wisinski	5/16/81		Ready to Run

December, 1983 Table of Approved Experiments (continued) - 2

Number	Title	Experimenters	Date Approved	Status
PEP-4 (TPC)	A PEP Facility Based on the Time Projection Chamber	LBL: M.Alston-Garnjost, A.Barbaro-Galtieri, A.Barnes, A.Bross, W.C. Carithers, O.Chamberlain, A.Clark, O.Dahl, C.Day, P.Eberhard, D.Fancher, R.Kenney, L.Kerth, S.Loken, G.Lynch, R.Madaras, R.Majka, P.Martin, J.Marx, P.Nemethy, D.Nygren, P.Oddone, M.Pripstein, P.Robrish, M.Ronan, R. Ross, G.Shapiro, M.Stevenson, W.Wenzel UCLA: C.Buchanan, J.Hauptman, D.Stork, W.Slater, H.Ticho YALE: M.Zeller UCR: W.Gorn, J. Layter, B. SHEN, G.VanDalen JOHNS-HOPKINS: B. Barnett B.Blumenfeld, C.-Y.Chien, L.Madansky, J. Matthews, A. Pevsner U. TOKYO: J.Chiba, H.Fujii, T. Fujii, T.Kamae	21 Jan. 1977	Upgrading
PEP-5 (MK II)	General Survey of Particle Production at PEP	SLAC: A.Boyarski, M.Breidenbach, D.Burke B.Delcourt, J. Dorenbosch, J.Dorfan, G.Feldman, G.Hanson, R. Hollebeek, W.Innes, J.Jaros, R.R.Larsen, B.Loehr, N. LOCKYER, V. Luth, M.Perl, B.Richter, A. Roussarie, D.Scharre, J.Siegrist, R.Vidal, J. Weiss LBL: G.Abrams, A.Blondel, W.Chinowsky, G.Gidal, G.Goldhaber, A.Johnson, J. Kadyk, A.Lankford, J.Strait, G.Trilling, I.Videau, Y.Wang, G.Zhao HARVARD: A.Baecker, C.Blocker, R. Schwitters	1/21/77	Running
PEP-6 (MAC)	A Lepton Total Energy Detector	U.COLORADO: W. Ford, J. Smith U.WISCONSIN: J.Johnson, R. Morse, R.Prepost, D. Wiser SLAC: W. Ash, G.Chadwick, P.Leung, S.Michalowski, D. Ritson U.UTAH: D.Groom, E. Loh NORTHEASTERN U; L.Baksay, H.Band, W.Faissler, M.Gettner, B.Gottschalk, J.Morimisato, D.Shambroom, E.VonGoeler, R. WEINSTEIN	1/21/77	Running

December, 1983 Table of Approved Experiments (continued) - 3

Number	Title	Experimenters	Date Approved	Status
PEP-9	PEP Forward Detector Facility (2-Gamma)	UCD: W. Ko, R.LANDER, D.Pellett, C. Williams UCSD: G.Masek, E.Miller, W.Vernon UCSB: V.Bharadwat, D.Caldwell, A.Eisner, A.Lu, R. Morrison, S. Yellin NIKHEF: J.Armitage, F.Erne, W.Langefeld, H.Paar, H.Sens, J.Timmer	21 Jan. 1977	Inactive/ Upgrading
PEP-12	High Resolution Spectrometer (HRS)	ANL: M.DERRICK, E.Fernandez, L.Hyman, R.Klem, P.Kooijman, S.Kooijman, J.Loos, L.Price INDIANA U.: G.Baranko, B.Brabson, G.Forden, S.Gray, J.-P.Guillaud, D.Koltick, H.Neal, H. Ogren, D. Rust U. MICHIGAN: C.Akerlof, J.Chapman, N.Harnew, D. MEYER, D.Nitz, D.Rubin, A.Seidl, R.Thun PURDUE: R.DeBonte, R.Jones, F.Loeffler, R. McIlwain, D.Miller, P.Ong, L.K.Rangan, E. Shibata, R.Stevens, B.Wilson, D.Wood LBL: B. Cork SLAC: L. Keller, J. Va'vra	29 Jan. 1978	Running
PEP-20	DELCO at PEP	CIT: B.Barish, S.-C. Geo, Y.-Z. Huang D.Koop, J.Ludwig, G.Mills, S.Sherman, R. Stroynowski, H. Yamamoto, SLAC: W.Atwood, P.Baillon, H.DeStaebler, H.Kichimi, A. Ogawa, D.Perret-Gallix, R.Pitthan, C.Prescott, L.Rochester, R. Taylor, S.-G.Wang, C.Young STANFORD U: G./Bonneaud, G.Donaldson, M.Duro, G.Irwin, J.KIRKBY, D. Pollard, S. Wojcicki, W.-G. Yan	9/8/78	Running
PEP-21	Search for Unseen States Using Photon Tagging	SLAC: D.BURKE, R.HOLLEBEEK, M.Jonker MIT: S. Whitaker U.WASH: R.Davisson, J.Rothberg, K.Young SUNY-STONY BROOK: P.Grannis	5/14/83	Planning/Set
SLC-6	MARK II at the SLC	SLAC: D.DORFAN, G.FELDMAN U. MICHIGAN LBL: G. TRILLING C.I.T., UC-SantaCruz, U.Hawaii	5/14/83	Planning

December, 1983 Table of Approved Experiments (continued) - 4

Number	Title	Experimenters		Date Approved	Status
D-24	SSRL Dedicated Time	SLAC/SSRL:	H. Winick	12/04/75	Planning
D-28	Resonance Radiation	STANFORD:	M. Piestrup	9/19/80	Planning
D-30	Channeling Radiation	SUNY-ALBANY	C.R. Sun	10/8/82	Planning
P-0	Operator Training	SLAC:	D. Tsang		Planning
P-1	Beam Dynamics Tests for the SLC	SLAC:	G.Loew, R.Miller, R.Stiening		Inactive
P-6	General Equipment Checkout	SLAC:	G. Loew		Test
P-7	Positron Source Tuneup	SLAC:	G. Loew, R.Miller	10/01/71	Test
P-9	SPEAR Tuning Test	SLAC:	G. Loew		Test
T-58	SPEAR Electron Storage Ring Tests	SLAC:	B.Richter, J.Rees, J.Harris	11/21/71	Running
T-172	Beam Line 6 Checkout	SLAC:	R. Gearhart	10/24/74	Inactive
T-276	Beam Line 27	SLAC:	J. Murray/K. Moffeit	11/15/79	Inactive
T-282	PEP Accelerator Studies	SLAC:	E. Paterson	1/18/80	Planning
T-296	19 Line Setup and Checkout	SLAC:	T. Fieguth	10/22/80	Inactive
T-298	PEP-12 Wire Calorimeter Test	ANL:	L. Price	10/27/80	Inactive
T-300	Cerenkov Ring Imaging Detector	SLAC:	S. Williams	1/13/81	Running

December, 1983 Table of Approved Experiments (continued) - 5

Number	Title	Experimenters		Date Approved		Status
T-313	SLC Damping Ring Checkout	SLAC:	S. Ecklund	12/22/81		Running
T-319	CCD Development	SLAC:	S. Shapiro	4/16/82		Running
T-321	Section 10 Profile Monitors	SLAC:	V. Luth	5/10/82		Planning ✓
T-328	Test of Cerenkov Counters for Identification	U. WASH.	V. Chaloupka	12/21/82		Inactive
T-338	MARK II/SLC Drift Chamber	SLAC:	A. Boyarski	5/19/83		Planning
T-343	BGO Calorimeter Test	NIKHEF:	J. C. Sens	9/12/83		Planning
T-344	Test of Lead Glass	KEK: SLAC:	K. Ogawa R. Gearhart	9/26/83		Planning
T-345	Test Background Rates in ESA	AMERICAN U.	R. Arnold	11/7/83		Running/Comp.
T-346	Test B/L 20/21 at Low Momenta	SLAC:	R. Gearhart S. Shapiro	11/9/83		Planning
T-348	SLD Drift Chamber Tests	SLAC:	C. Prescott	11/29/83		Planning
T-349	SLC Calorimeter Tests	U. WASH. U. WISC.	P. Mockett J. Johnson	11/17/83		Planning
T-351	Energy Calibration for E-137	VPI:	L. Mo	12/16/83		Construction

STATUS:
Running = Experiment is in data collection phase and was a prime user of accelerator time.
Checkout = Experiment is in checkout phase and used accelerator time for checkout purposes.
Setup = Experiment was being setup in the research yard, or PEP I.R.
Inactive = Experiment was inactive in the research yard.
Construction = Experiment and/or beam is under construction.
Ready to Run = Experiment ready for future scheduled run.
Parasiting = Used parasite beam time.
Complete = Experiment completed.
Test = Test run performed.
Planning = In design & planning stage.
Upgrading = Experimental equipment is being upgraded.
Repair = Down for Equipment Repair

3. ACCELERATOR IMPROVEMENTS

A. Nuclear Physics Injector

Authorization to proceed on the Nuclear Physics Injector Project has been received from the Department of Energy. The project team has been organized, and preparation of designs and specifications for components is underway.

4. RESEARCH DIVISION DEVELOPMENTS

A. Data Analysis Group Activity

Hardware: The upgrade kit to convert the TPC VAX-11/780 computer system into a dual-processor 11/782 was received but not installed.

An engineering change for the bus interface used on most of the VAX 6250 bpi tape drive systems was received; it is designed to cure some annoying problems encountered when backing-up disk files. A schedule for testing and installation has yet to be worked out.

A used tape drive was purchased from the Dutch group collaborating in the PEP-9 experiment and was installed on the Test Beam Facility 11/750 computer.

An entire 11/750 computer system belonging to the PEP-9 Dutch group was borrowed and relocated in the second floor of the Computer Building, for use as a data acquisition system for PEP-21. It should be returned early in February, when the "real" PEP-21 system is scheduled to arrive. An electrostatic printer/plotter for this experiment has been received and installed.

Ethernet cable was installed between IR-4 and IR-8 at PEP.

Software: There were no significant software milestones this month.

Operations: In December 247 events were measured in 82 hours and 64,072 frames scanned in 476 hours.

The total headcount for scanners dropped to 5.0 FTE by the end of the month. (J. Brown)

5. PEP DEVELOPMENTS

A. PEP Activities

PEP ran moderately well throughout the month until the scheduled two week Christmas shutdown which began December 23. The average luminosity per shift improved to 170 nb^{-1} which is still considerably less than was achieved last year.

The major activities planned for the Christmas shutdown included the installation of interaction region chamber for the new experiment PEP-21, the installation of a new synchrotron radiation mask assembly for the two-photon experiment and the nitriding of an RF cavity to suppress multipactor. (E. Paterson)

	Hours	% of Scheduled Operating Time
Scheduled Downtime	228	
Scheduled Operating Time	516	
Hours This Month	744	
Ring Downtime	84	16.4
Linac Downtime	80	15.5
Colliding Beams + Fill + Tune	352	68.1

B. SPEAR

SPEAR continued running through December for SSRL, typically at 80 mA peak current at 3 GeV. Further work was done towards understanding the low luminosity in colliding beams. It was established that the luminosity monitor had suffered a slow degradation of sensitivity of 30–50% over a period of six to nine months. This was not sufficient to explain the factor of 2.5 to 3 loss of expected data rate experienced in October, but taken together with other minor improvements in luminosity performance was enough to show promise that colliding beam performance would be in the normal range when the machine starts up in January.

In other machine physics, several attempts were made to inject into the low emittance configuration, with only limited success. The new 54-pole hybrid wiggler (developed by SSRL/Exxon/LBL) has been characterized and shown to be compatible with storage ring operation. (J. Harris)

PUBLICATIONS ISSUED

SLAC-PUB-3225
PRODUCTION OF SCALAR LEPTONS IN W AND Z BOSON DECAY.
By R.Michael Barnett (Santa Barbara, ITP), Howard E. Haber (UC, Santa Cruz & SLAC), Klaus S. Lackner (SLAC), SLAC-PUB-3225, Oct 1983. 43pp.
Submitted to Phys. Rev. D

SLAC-PUB-3243
STUDY OF HEAVY QUARK PRODUCTION WITH THE MARK-II AT PEP.
By G.S. Abrams, D. Amidei, A. Baden, C. de la Vaissiere, G. Gidal, M. Gold, G. Goldhaber, L. Golding, D. Herrup, I. Juricic, J. Kadyk, M.E. Nelson, P.C. Rowson, H. Schellman, P.D. Sheldon, G. Trilling (LBL, Berkeley), Adam M. Boyarski, Martin Breidenbach, P. Burchat, D.L. Burke, J. Dorfan, L. Dunn, G. Feldman, L. Gladney, G. Hanson, R.J. Hollebeek, W.R. Innes, J. Jaros, M. Jonker, S. Klein, A.J. Lankford, Rudolf R. Larsen, B.W. LeClaire, N. Lockyer, V. Luth, C. Matteuzzi, R.A. Ong, Martin L. Perl, N. Phinney, J. Price, Burton Richter, Marc Ross, D. Schlatter, J. Smith, J.M. Yelton, C. Zaiser (SLAC), C.A. Blocker, M.W. Eaton, M.E. Levi, R. Schwitters, T. Schaad (Harvard U.), SLAC-PUB-3243, Oct 1983. 15pp.
Presented at the 7th Int. Conf. on Meson Spectroscopy, Upton, N.Y., Apr 14-16, 1983.

SLAC-PUB-3251
A STUDY OF Z0 DECAYS INTO LEPTON PAIRS AND QUARK PAIRS.
By Pat Kalyniak (SLAC), John N. Ng, P. Zakarauskas (TRIUMF & British Columbia U.), SLAC-PUB-3251, Nov 1983. 20pp.
Submitted to Phys. Rev. D

SLAC-PUB-3253
CASIMIR ENERGY OF A SCALAR FIELD WITH A SPACE-DEPENDENT MASS DISTRIBUTION.
By Hideaki Aoyama (SLAC), SLAC-PUB-3253, Nov 1983. 30pp.

SLAC-PUB-3255
PARTIAL BREAKING OF EXTENDED SUPERSYMMETRY.
By Jonathan Bagger (Karlsruhe U., ITP & SLAC), Julius Wess (Rockefeller U. & Karlsruhe U., ITP), SLAC-PUB-3255, Nov 1983. 14pp.
Submitted to Phys. Lett.

SLAC-PUB-3257
MEASUREMENTS OF THE A-DEPENDENCE OF DEEP INELASTIC ELECTRON SCATTERING FROM NUCLEI.
By R.G. Arnold, P. Bosted, C.C. Chang, J. Gomez, A.T. Katramatou, G. Petratos, A.A. Rahbar, Stephen Rock, A.F. Sill, Z.M. Szalata (American U.), A. Bodek, N. Giokaris (Rochester U.), D. Sherden (SLAC), B.A. Mecking (Bonn U.), R.M. Lombard (Saclay), SLAC-PUB-3257, Nov 1983. 15pp.
Submitted to Phys. Rev. Lett.

SLAC/AP-008
STABILITY OF THE COHERENT QUADRUPOLE OSCILLATIONS EXCITED BY THE BEAM-BEAM INTERACTION.
By Yukihide Kamiya, A.W. Chao (SLAC), SLAC/AP-008, Oct 1983. 22pp.

OTHER PUBLICATIONS BY SLAC AUTHORS

CERN-TH-3747
... AND FOR OUR NEXT SPECTROSCOPY?
By John Ellis (SLAC & CERN), CERN-TH-3747, Oct 1983. 64pp.
Presented at 11th SLAC Summer Inst. on Particle Physics, Stanford, CA, Jul 18-26, 1983.

STANFORD LINEAR ACCELERATOR CENTER
MONTHLY REPORT FOR JANUARY 1984

I. ACCELERATOR AND RESEARCH OPERATIONS

A. OPERATING HOURS (Manned Hours)

Physics Beam Hours:(1) (Machine and Particle Physics) .... Total 489

Non-Physics Hours: Scheduled Downtime 0, Unscheduled Downtime 47. Total 47

TOTAL OPERATING HOURS 536

B. ELECTRON PULSES GENERATED

Total 1.2×10^8 Average 60 PPS

C. EXPERIMENTAL HOURS(2)

1. Particle Physics

EXPERIMENTAL AREA OR BEAMLINE(3)		EXPERIMENTAL TIME (Actual Hours)	TEST AND CHECKOUT HOURS	TOTAL EXPERIMENT HOURS
PEP				
	IR- 2			
	IR- 4	375		375
	IR- 6	385		385
	IR- 8	385		385
	IR-10			
	IR-12	385		385
SPEAR				
	EAST PIT			
	WEST PIT	336		336
ESA	3			
ESB	19		53	53
	20		37	37
	14			
	8			
ESC	27			
	26/6			
TOTAL		1866	90	1956

2. Machine Physics

PEP 0, SPEAR 216, LINAC 463. 679

3. SSRL (Dedicated Time at SPEAR)[4] 0

TOTAL EXPERIMENTAL HOURS 2635

Where is SLC in all this.

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[1] Number of hours accelerator is run with one or more beams excluding accelerator beam tune-up and other non-physics beam time.

[2] Number of hours an experiment is run including actual beam hours and beam downtime "normal to the experiment."

[3] Refer to Figures 1 and 2 for beamline locations and experimental areas.

[4] Accelerator beam available to SPEAR storage ring, for SSRL use.

D. OVERALL EXPERIMENTAL PROGRAM STATUS

1. Electronic Experiments

	Factored Hours*
Approved research hours at beginning of month	256
Hours run during the month	-
New hours approved during the month	-
Approved hours remaining at end of month:	256

2. PEP and SPEAR Experiments

	Actual Hours PEP	Actual Hours SPEAR
Approved research hours at beginning of month	-	2127
Hours run during the month	1530	356
New hours approved during the month	-	-
Approved hours remaining at end of month:	-	1791

E. BEAM INTENSITY

Peak	20 mA
Average	2.73 μA

F. KLYSTRON EXPERIENCE

Total Klystron Hours	148,527
Number of Klystron Failures	1

G. DATA ANALYSIS

Bubble Chamber Events Measured	270

H. COMPUTER OPERATIONS (Manned Hours) 3081

Computation Hours	
SLAC Facility Group	1
User Groups	739
Total Computation Hours:	740
Non-Computation Hours	
Scheduled Maintenance	
Scheduled Modifications	
Unscheduled Downtime and Reruns	4
Idle Time	
Utility Failure	
Total Non-Computation Hours:	4
TOTAL MANNED HOURS:	744

I. SPECIAL OPERATION FEATURES

After a turn-on and hot maintenance period, Cycle 84-2 began on January 9, 1984. During the month, the accelerator was manned for 67 shifts at 60 pps. A total of 26 shifts of "dedicated" and "semidedicated" runs for the SLAC Linear Collider were run during operations in January.

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* Factored hours are represented by the formula $T_c = T_0(R+20)/200$ where T_c = charged hours, T_0 = total hours beam was available to the experimenter for both check-out and data taking, and R = the average pulse repetition rate. Maximum for $(R+20)/200$ is 1.5 even if the calculated amount exceeds this value.

2. EARCH AREA AND EXPERIMENT STATU

A. General

The accelerator began operation at 60 pps on January 2 following a ten-day shutdown. The first week of the month was dedicated to the Sector 10 test for SLC development. During that period the installation of a new vacuum chamber and some detector components for PEP-21 (Anomalous Single Photon) was completed in IR-10. In IR-2 a new mask was installed for Two-Gamma to test a BGO detector for tagging small angle (4-10 mrad) electrons. PEP began operation for MARK II, MAC, HRS and DELCO on January 10 and accumulated about five inverse picobarns during the month. After a slow start, SPEAR operated the entire month for MARK III.

SLC testing continued at the rate of about one shift per day throughout the month. This running was not compatible with test beams, so very little test beam running occurred and a large backlog now exists in the three test beams. (L. Keller)

B. Program Status and Reports of Experiments & Tests

Figure 1 is a research area plan showing the location of experiments and facilities. Figure 2 shows locations of the experimental beam lines in the research area. Figure 3 shows the long-range schedule. Table I is a list of presently approved high-energy experiments. The right-hand column of Table I gives the status and activity of each experiment during the cycle.

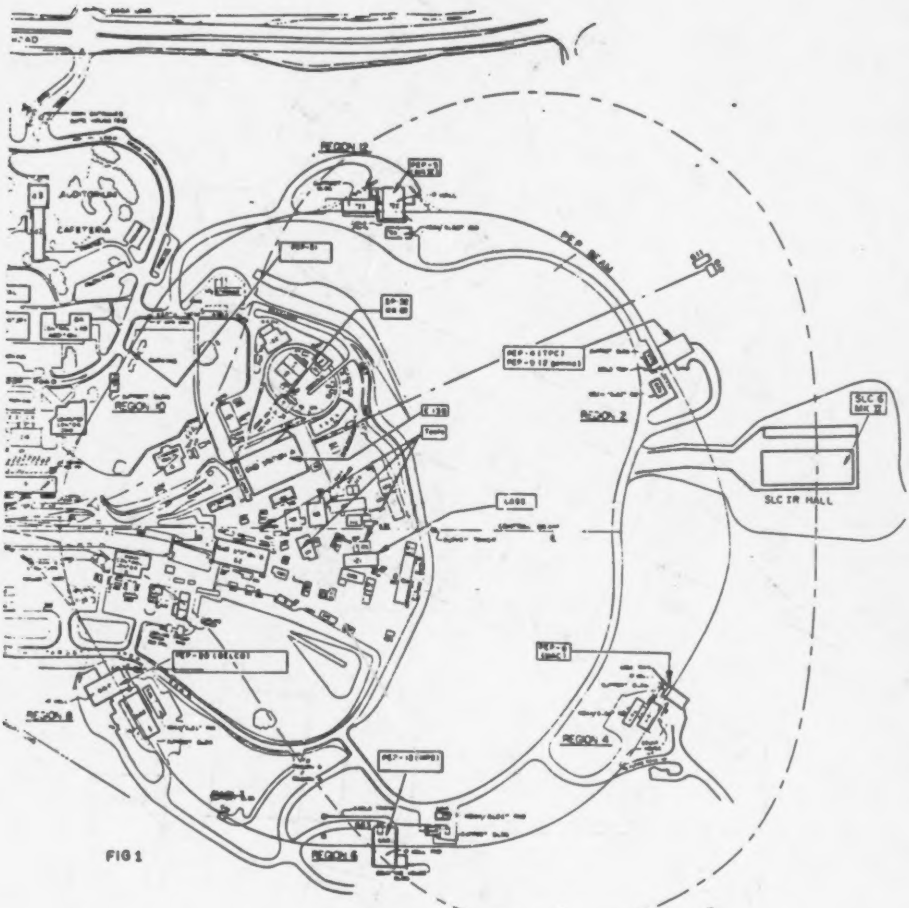
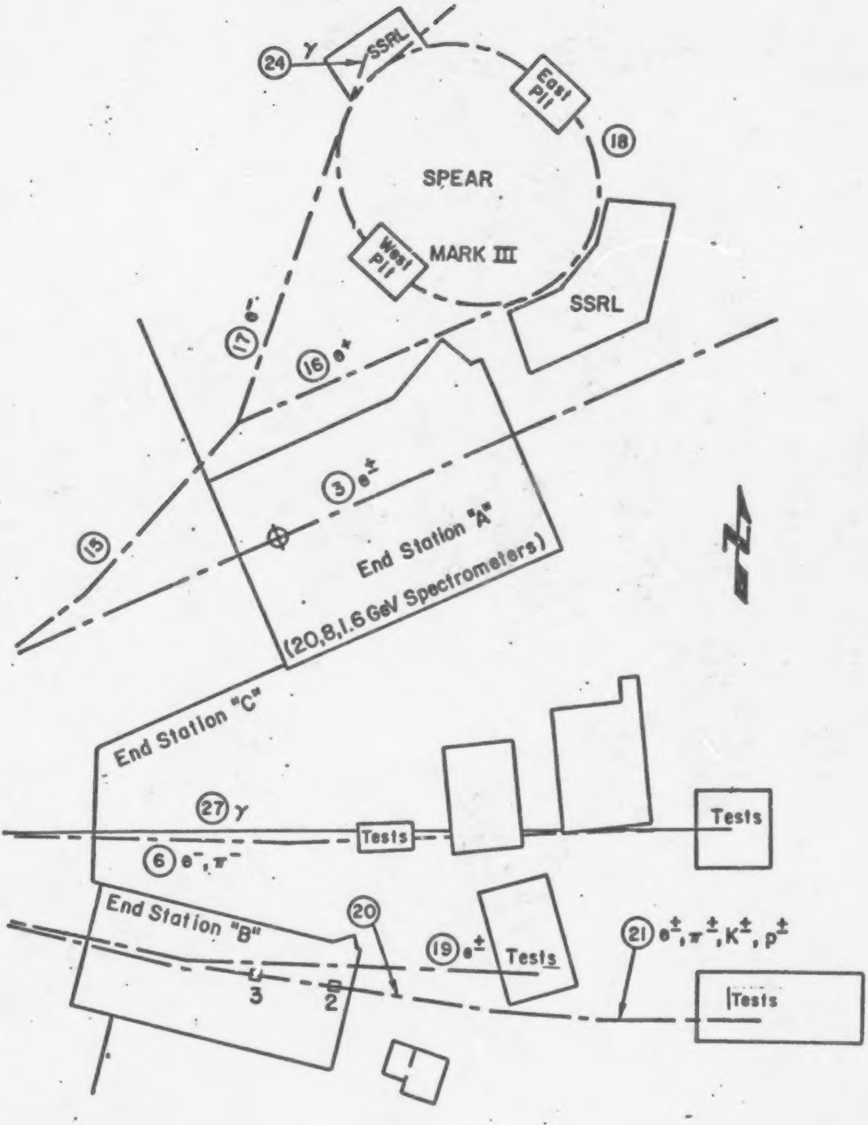

REGION 12
AUDITORIUM
CAFETERIA
PEP BEAM
REGION 10
PEP-4 (TPC)
PEP-9 (2 gamma)
REGION 2
SLC 6
MK II
SLC IR HALL
PEP-6 (MAC)
REGION 4
REGION 8
REGION 6

FIG 1



24
γ
SSRL
East Pit
18
SPEAR
MARK III
West Pit
SSRL
17 e⁻
16 e⁺
3 e±
15
End Station "A"
(20,8,1.6 GeV Spectrometers)
End Station "C"
27 γ
Tests
Tests
6 e⁻, π⁻
End Station "B"
20
19 e±
Tests
21 e±, π±, K±, p±
Tests
3
2
1
N

—□— RF Separator

FIG 2

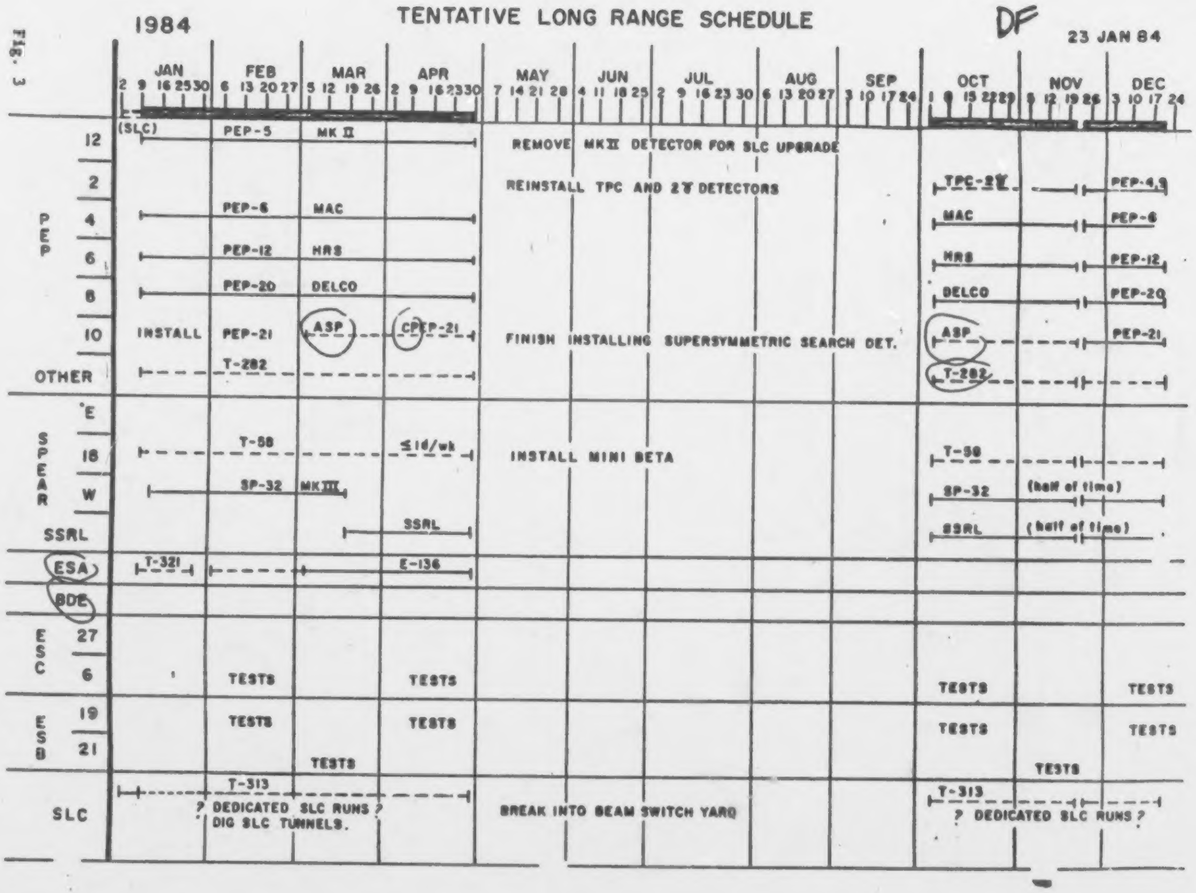

1984
TENTATIVE LONG RANGE SCHEDULE
DF
23 JAN 84
JAN 2 9 16 25 30
FEB 6 13 20 27
MAR 5 12 19 26
APR 2 9 16 23 30
MAY 7 14 21 28
JUN 4 11 18 25
JUL 2 9 16 23 30
AUG 6 13 20 27
SEP 3 10 17 24
OCT 1 8 15 22 29
NOV 5 12 19 26
DEC 3 10 17 24
PEP
12
2
4
6
8
10
OTHER
SPEAR
E
18
W
SSRL
ESA
BDE
ESC
27
6
ESB
19
21
SLC
(SLC)
PEP-5
MK II
REMOVE MK II DETECTOR FOR SLC UPGRADE
REINSTALL TPC AND 2γ DETECTORS
TPC-2γ
PEP-4,9
PEP-6
MAC
PEP-12
HRS
PEP-20
DELCO
INSTALL
PEP-21
ASP
CPEP-21
FINISH INSTALLING SUPERSYMMETRIC SEARCH DET.
T-282
T-58
≤1d/wk
INSTALL MINI BETA
SP-32
MK III
(half of time)
SSRL
T-321
E-136
TESTS
T-313
? DEDICATED SLC RUNS ?
DIG SLC TUNNELS.
BREAK INTO BEAM SWITCH YARD

Fig. 3

STANFORD LINEAR ACCELERATOR CENTER

January, 1984

TABLE 1

TABLE OF APPROVED EXPERIMENTS

Number	Title	Experimenters	Date Approved		Status
			Stage 1	Stage 2	
E-136	Elastic Electron-Proton Cross Sections at High Momentum Transfer	AMERICAN U.: R. ARNOLD, P.Bosted, S. Rock, Z.M. Szalata U. BONN: B. A. Mecking SLAC: D. J. Sherden	5/16/81		Ready to Run
SP-32	Studies of the Weak Decays of D Mesons at the ψ'' Resonance	C.I.T.: R.Baltrusaitis, J.Hauser, D. HITLIN, J.Richman, J.J.Russell SLAC: K.Bunnell, D.Coward, K.Einsweiler, D.Hutchinson, R.Mozley, A.Odian, J.Roehrig, W.Toki, Y. Unno, F. Villa UCSC: H.Bledsoe, D.Dorfan, R.Fabrizio, F.Grancagnolo, R.Hamilton, C.Heusch, T.Schalk, H.Sadrozinski, A. Seiden, D. Smith U. ILLINOIS: J.Becker, R.Cassell, H.Cui, B.Eisenstein, G.Gladding, S.Plaetzer, A.Spadafora, J.Thaler, A.Wattenberg, W.Wisniewski U. WASH.: J.Brown, T.Burnett, V.Cook, C.delPapa, H.Lubatti, K.Moriyasu, J.Rothberg, J.Sleeman, H. Willutzki, D. Wisinski	5/16/81		Running

January, 1984 Table of Approved Experiments (continued) - 2

Number	Title	Experimenters	Date Approved		Status
PEP-4 (TPC)	A PEP Facility Based on the Time Projection Chamber	LBL: M.Alston-Garnjost, A.Barbaro-Galtieri, A.Barnes, A.Bross, W.C. Carithers, O.Chamberlain, A.Clark, O.Dahl, C.Day, P.Eberhard, D.Fancher, R.Kenney, L.Kerth, S.Loken, G.Lynch, R.Madaras, R.Majka, P.Martin, J.Marx, P.Nemethy, D.Nygren, P.Oddone, M.Pripstein, P.Robrish, M.Ronan, R. Ross, G.Shapiro, M.Stevenson, W.Wenzel UCLA: C.Buchanan, J.Hauptman, D.Stork, W.Slater, H.Ticho YALE: M.Zeller UCR: W.Gorn, J. Layter, B. SHEN, G.VanDalen JOHNS-HOPKINS: B. Barnett B.Blumenfeld, C.-Y.Chien, L.Madansky, J. Matthews, A. Pevsner U. TOKYO: J.Chiba, H.Fujii, T. Fujii, T.Kamae	21 Jan. 1977		Upgrading
PEP-5 (MK II)	General Survey of Particle Production at PEP	SLAC: A.Boyarski, M.Breidenbach, D.Burke B.Delcourt, J. Dorenbosch, J.Dorfan, G.Feldman, G.Hanson, R. Hollebeek, W.Innes, J.Jaros, R.R.Larsen, B.Loehr, N. LOCKYER, V. Luth, M.Perl, B.Richter, A. Roussarie, D.Scharre, J.Siegrist, R.Vidal, J. Weiss LBL: G.Abrams, A.Blondel, W.Chinowsky, G.Gidal, G.Goldhaber, A.Johnson, J. Kadyk, A.Lankford, J.Strait, G.Trilling, I.Videau, Y.Wang, G.Zhao HARVARD: A.Baecker, C.Blocker, R. Schwitters	1/21/77		Running
PEP-6 (MAC)	A Lepton Total Energy Detector	U.COLORADO: W. Ford, J. Smith U.WISCONSIN: J.Johnson, R. Morse, R.Prepost, D. Wiser SLAC: W. Ash, G.Chadwick, P.Leung, S.Michalowski, D. Ritson U.UTAH: D.Groom, E. Loh NORTHEASTERN U; L.Baksay, H.Band, W.Faissler, M.Gettner, B.Gottschalk, J.Morimisato, D.Shambroom, E.VonGoeler, R. WEINSTEIN	1/21/77		Running

January, 1984   Table of Approved Experiments (continued) - 3

Number	Title	Experimenters	Date Approved	Status
PEP-9	PEP Forward Detector Facility (2-Gamma)	UCD: W. Ko, R.LANDER, D.Pellett, C. Williams UCSD: G.Masek, E.Miller, W.Vernon UCSB: V.Bharadwaj, D.Caldwell, A.Eisner, A.Lu, R. Morrison, S. Yellin NIKHEF: J.Armitage, F.Erne, W.Langefeld, H.Paar, H.Sens, J.Timmer	21 Jan. 1977	Inactive/ Upgrading
PEP-12	High Resolution Spectrometer (HRS)	ANL: H.DERRICK, E.Fernandez, L.Hyman, R.Klem, P.Kooijman, S.Kooijman, J.Loos, L.Price INDIANA U.: G.Baranko, B.Brabson, G.Forden, S.Gray, J.-P.Guillaud, D.Koltick, H.Neal, H. Ogren, D. Rust U. MICHIGAN: C.Akerlof, J.Chapman, N.Harnew, D. MEYER, D.Nitz, D.Rubin, A.Seidl, R.Thun PURDUE: R.DeBonte, R.Jones, F.Loeffler, R. McIlwain, D.Miller, P.Ong, L.K.Rangan, E. Shibata, R.Stevens, B.Wilson, D.Wood LBL: B. Cork SLAC: L. Keller, J. Va'vra	29 Jan. 1978	Running
PEP-20	DELCO at PEP	CIT: B.Barish, S.-C. Gao, Y.-Z. Huang D.Koop, J.Ludwig, G.Mills, S.Sherman, R. Stroynowski, H. Yamamoto, SLAC: W.Atwood, P.Baillon, H.DeStaebler, H.Kichimi, A. Ogawa, D.Perret-Gallix, R.Pitthan, C.Prescott, L.Rochester, R. Taylor, S.-Q.Wang, C.Young STANFORD U: G./Bonneaud, G.Donaldson, M.Duro, G.Irwin, J.KIRKBY, D. Pollard, S. Wojcicki, W.-G. Yan	9/8/78	Running
PEP-21	Search for Unseen States Using Photon Tagging	SLAC: D.BURKE, R.HOLLEBEEK, M.Jonker MIT: S. Whitaker U.WASH: R.Davisson, J.Rothberg, K.Young SUNY-STONY BROOK: P.Grannis	5/14/83	Planning/Setup
SLC-6	MARK II at the SLC	SLAC: D.DORFAN, G.FELDMAN U. MICHIGAN LBL: G. TRILLING C.I.T., UC-SantaCruz, U.Hawaii	5/14/83	Planning

January, 1984   Table of Approved Experiments (continued) - 4

Number	Title	Experimenters		Date Approved	Status
D-24	SSRL Dedicated Time	SLAC/SSRL:	H. Winick	12/04/75	Planning
D-28	Resonance Radiation	STANFORD:	M. Piestrup	9/19/80	Planning
D-30	Channeling Radiation	SUNY-ALBANY	C.R. Sun	10/8/82	Planning
P-0	Operator Training	SLAC:	D. Tsang		Planning
P-1	Beam Dynamics Tests for the SLC	SLAC:	G.Loew, R.Miller, R.Stiening		Inactive
P-6	General Equipment Checkout	SLAC:	G. Loew		Test
P-7	Positron Source Tuneup	SLAC:	G. Loew, R.Miller	10/01/71	Test
P-9	SPEAR Tuning Test	SLAC:	G. Loew		Test
T-58	SPEAR Electron Storage Ring Tests	SLAC:	B.Richter, J.Rees, J.Harris	11/21/71	Running
T-172	Beam Line 6 Checkout	SLAC:	R. Gearhart	10/24/74	Inactive
T-276	Beam Line 27	SLAC:	J. Murray	11/15/79	Inactive
T-282	PEP Accelerator Studies	SLAC:	E. Paterson	1/18/80	Planning
T-296	19 Line Setup and Checkout	SLAC:	T. Fieguth	10/22/80	Inactive
T-298	PEP-12 Wire Calorimeter Test	ANL:	L. Price	10/27/80	Inactive
T-300	Cerenkov Ring Imaging Detector	SLAC:	S. Williams	1/13/81	Running

January, 1984 Table of Approved Experiments (continued) - 5

Number	Title	Experimenters		Date Approved	Status
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T-319	CCD Development	SLAC:	S. Shapiro	4/16/82	Running
T-321	Section 10 Profile Monitors	SLAC:	V. Luth	5/10/82	Planning
T-328	Test of Cerenkov Counters for Identification	U. WASH.	V. Chaloupka	12/21/82	Inactive
T-338	MARK II/SLC Drift Chamber	SLAC:	A. Boyarski	5/19/83	Planning
T-343	BGO Calorimeter Test	NIKHEF:	J. C. Sens	9/12/83	Running/Comp.
T-344	Test of Lead Glass	KEK: SLAC:	K. Ogawa R. Gearhart	9/26/83	Planning
T-346	Test B/L 20/21 at Low Momenta	SLAC:	R. Gearhart S. Shapiro	11/9/83	Planning
T-348	SLD Drift Chamber Tests	SLAC:	C. Prescott	11/29/83	Planning
T-349	SLC Calorimeter Tests	U. WASH. U. WISC.	P. Mockett J. Johnson	11/17/83	Planning
T-351	Energy Calibration for E-137	VPI:	L. Mo	12/16/83	Construction
T-352	Lead-Lucite Shower Counter Test	PRINCETON:	G. Gollin	1/26/84	Planning

STATUS:
Running = Experiment is in data collection phase and was a prime user of accelerator time.
Checkout = Experiment is in checkout phase and used accelerator time for checkout purposes.
Setup = Experiment was being setup in the research yard, or PEP I.R.
Inactive = Experiment was inactive in the research yard.
Construction = Experiment and/or beam is under construction.
Ready to Run = Experiment ready for future scheduled run.
Parasiting = Used parasite beam time.
Complete = Experiment completed.
Test = Test run performed.
Planning = In design & planning stage.
Upgrading = Experimental equipment is being upgraded.
Repair = Down for Equipment Repair

3. ACCELERATOR IMPROVEMENT

A. Nuclear Physics Injector

The designs of many of the components for the mechanical system are complete, and fabrication has been initiated. The layout design for the placement of instrumentation in the gallery and alcove areas is near completion. Rack locations for specific equipment have been assigned. Some long lead delivery items are on order, and many CAMAC type modules and racks have been procured.

4. RESEARCH DIVISION DEVELOPMENTS

A. Data Analysis Group Activity

Hardware: a new VAX-11/750 computer for use by PEP-21 as a data acquisition system was received but not installed. It has 900 megabytes of disk storage, a "streaming" tape drive, and four megabytes of physical memory.

A short Ethernet segment was run from the Computer Building to Building 283 (a new temporary building near Cryogenics) to handle terminal connections.

We finally managed to learn how to correctly upgrade Ann Arbor Ambassador terminals and their add-on graphics attachment (the so-called Graphics Master) so that they have the latest firmware or PROM set. The lab has ordered over forty Graphics Masters in the last few months, almost all of which will require upgrading to function in a useful way.

Software: There were no significant software milestones this month.

Operations: In January 270 events were measured in 103 hours on the NRI system and 63,446 frames scanned in 500 hours. Four additional students began working part-time during the month, increasing the total scanner headcount to 5.6 full-time equivalents. (J. Brown)

5. PEP DEVELOPMENTS

A. PEP Activities

After the Christmas shutdown, PEP began operation as scheduled, in the week beginning January 9th. During the remaining part of the month, PEP performance improved steadily to the point where 300 nb^{-1}/shift in integrated luminosity became almost the norm.

During the downtime one RF cavity was internally resputtered with titanium nitride to suppress multipactoring. This was the first time this had been tried, in situ, in the tunnel and proved to be very successful. As there is growing evidence that the original coating appears to be disappearing after years of operation, we plan to recoat many more cavities during the summer downtime. (E. Paterson)

	Hours	% of Scheduled Operating Time
Scheduled Downtime	212	
Scheduled Operating Time	532	
Hours This Month	744	
Ring Downtime	41	8
Linac Downtime	106	20
Colliding Beams + Fill + Tune	385	72

6. PUBLICATIONS ISSUED

SLAC-PUB-3222
THE MARK-III SPECTROMETER.
By D. Bernstein, Jeremy Bernstein, K. Bunnell, G. Burgueno, R. Cassell, B. Collins, D.H. Coward, K. Einsweiler, R.L. Eisele, B. Haber, D. Hutchinson, G. Mazaheri, E. McNerney, L. Moss, Robert F. Mozley, A. Odian, J. Roehrig, K. Skarpaas, B. Sukiennicki, W. Toki, Y. Unno, F. Villa, W. Wadley, Norbert Wermes, D. Wisinski (SLAC), R.M. Baltrusaitis, G. Belyansky, D. Coffman, R.K. Cooper, W. Freidler, H. Grau, J. Hauser, D. Hitlin, J. Richman, J.J. Russell, R.H. Schindler (Cal Tech.), J. Becker, G. Blaylock, H. Cui, B. Eisenstein, G. Gladding, J. Kohlmeier, S. Plaetzer, V. Simaitis, A. Spadafora, J. Thaler, A. Wattenberg, W. Wisniewski (Illinois U., Urbana), H. Bledsoe, David E. Dorfan, R. Fabrizio, F. Grancagnolo, R. Hamilton, C.A. Heusch, W. Hillson, J. Perrier, W. Rowe, H.F.W. Sadrozinski, M. Scarlatella, T. Schalk, A. Seiden, D.B. Smith (UC, Santa Cruz), J. Brown, T. Burnett, V. Cook, C. Del Papa, A.L. Duncan, D. Forbush, H. Guldenmann, P.M. Mockett, A. Nappi, J. Sleeman, F. Toeus, H. Willutzki (Washington U., Seattle), SLAC-PUB-3222, Dec 1983. 72pp.
Submitted to Nucl. Instrum. Methods

SLAC-PUB-3235-Rev.
TEST OF LEAD GLASS SHOWER COUNTERS.
By K. Ogawa, R. Sugahara, K. Takahashi, F. Takasaki, T. Tauchi (KEK, Tsukuba), N. Awaji, H. Hayashii, S. Iwata, H. Ozaki, S. Suzuki (Nagoya U.), R. Gearhart, A. Miyamoto, T. Shimomura (SLAC), SLAC-PUB-3235-Rev., Oct 1983. 4pp.
Revised version.
Contributed to Nuclear Science Symposium, San Francisco, CA, Oct 19-21, 1983.

SLAC-PUB-3242
JETS IN e+ e- ANNIHILATION.
By R.J. Hollebeek (SLAC), SLAC-PUB-3242, Oct 1983. 120pp.
Presented at 11th SLAC Summer Inst. on Particle Physics, Stanford, CA, Jul 18-29, 1983.

SLAC-PUB-3250
FRAGMENTATION OF QUARKS AND GLUONS: TESTS OF QCD IN e+ e- ANNIHILATION.
By J. Dorfan (SLAC), SLAC-PUB-3250, Oct 1983. 56pp.
Invited talk given at 1983 Int. Symp. on Lepton and Photon Interactions at High Energy, Ithaca, N.Y., Aug 4-9, 1983.

SLAC-PUB-3258
DIFFICULTIES FOR THE EVOLUTION OF PURE STATES INTO MIXED STATES.
By T. Banks, Leonard Susskind (Stanford U., Phys. Dept.), Michael E. Peskin (SLAC), SLAC-PUB-3258, Dec 1983. 17pp.
Submitted to Nucl. Phys. B

SLAC-PUB-3259
PROGRAM FOR A CONSTRUCTIVE PHYSICS.
By H.Pierre Noyes (SLAC & Tubingen U.), Christopher Gefwert (Stanford U., Phys. Dept.), Michael J. Manthey (New Mexico U.), SLAC-PUB-3259, Nov 1983. 22pp.
To appear in Proc. of 7th Int. Congress on the Logic, Methodology ad Philosophy of Science, Salzburg, Austria, Jul 3-9, 1983.

SLAC-PUB-3260
RECENT RESULTS FROM DELCO.
By W.B. Atwood, P. Baillon, Barry C. Barish, Gerard Bonneaud, H.C. DeStaebler, G. Donaldson, R. Dubois, M. Duro, E.E. Elsen, S.G. Gao, Y.Z. Huang, G. Irwin, R.P. Johnson, H. Kichimi, J. Kirkby, D.E. Klem, D.E. Koop, J. Ludwig, G.B. Mills, A. Ogawa, T. Pal, D. Perret-Gallix, R. Pitthan, D.L. Pollard, C.Y. Prescott, L.Z. Rivkin, L.S. Rochester, W. Ruckstuhl, M. Sakuda, S.S. Sherman, E.J. Siskind, R. Stroynowski, S.Q. Wang, Stanley G. Wojcicki, H. Yamamoto, W.G. Yen, C. Young (Cal Tech & SLAC & Stanford U., Phys. Dept.), SLAC-PUB-3260, Nov 1983. 31pp.
Presented at 11th SLAC Summer Inst. on Particle Physics, Stanford, CA, Jul 18-26, 1983.

SLAC-PUB-3262
MARK-III RESULTS FROM SPEAR.
By MARK-III Collaboratio (SLAC), SLAC-PUB-3262, Nov 1983. 50pp.
Presented at 11th SLAC Summer Inst. on Particle Physics, Stanford, CA, Jul 18-26, 1983.

SLAC-PUB-3265
HARMONIC MAPS AND THEIR APPLICATION TO GENERAL RELATIVITY.
By Yishi Duan (SLAC), SLAC-PUB-3265, Dec 1983. 13pp.
Submitted to Phys. Lett. B

SLAC-PUB-3266
PROMPT ELECTRON PRODUCTION IN e+ e- ANNIHILATION AT 29-GeV.
By DELCO Collaboratio (Cal Tech & SLAC & Stanford U., Phys. Dept.), SLAC-PUB-3266, Dec 1983. 14pp.
Submitted to Phys. Rev. Lett.

SLAC-PUB-3267
CHIRAL SYMMETRY BREAKING IN A COMPOSITE MODEL WITH SCALARS BASED ON LATTICE GAUGE THEORY.
By Pisin Chen (SLAC), Charles B. Chiu (Texas U.), SLAC-PUB-3267, Dec 1983. 34pp.
Submitted to Phys. Rev. D

SLAC-PUB-3269
MODELS WHICH ALLOW A 'NEW INFLATIONARY' UNIVERSE HISTORY.
By Subhash Gupta (Princeton, Inst. Advanced Study), Helen R. Quinn (SLAC), SLAC-PUB-3269, Dec 1983. 23pp.
Submitted to Phys. Rev. D

SLAC-PUB-3270
PATH INTEGRALS WITHOUT LATTICES.
By Kevin Cahill, Randolph Reeder (New Mexico U. & SLAC), SLAC-PUB-3270, Dec 1983. 8pp.
Submitted to Phys. Lett. B

SLAC-PUB-3271
CHARM PHOTOPRODUCTION AT 20-GeV.
By SLAC Hybrid Facility Photon Collaboratio (Birmingham U. & Brown U. & Duke U. & Florida State U. & Imperial Coll., London & KEK, Tsukuba & MIT, LNS & Nara Womens U. & Oak Ridge & Rutherford & SLAC & Technion & Tohoku U. & Tufts U. & UC, Berkeley & Tel Aviv U. & Tennessee U. & Weizmann Inst.), SLAC-PUB-3271, Dec 1983. 74pp.
Submitted to Phys. Rev. D

SLAC-PUB-3275
SINGLE WEAK BOSON PRODUCTION IN ELECTRON - POSITRON ANNIHILATION.
By Mituaki Katuya (SLAC), Takayuki Miuya (KEK, Tsukuba), SLAC-PUB-3275, Dec 1983. 13pp.
Submitted to Phys. Lett. B

SLAC-PUB-3278
NOTE ON REVERSIBLE DISPERSION MATCHING WITH ARBITRARY PHASE ADVANCE.
By Richard H. Helm (SLAC), SLAC-PUB-3278, Jan 1984. 2pp.
Presented at SSC Workshop: On Accelerator Physics, Issue for a Superconducting Super Collider, Ann Arbor, MI, Dec 12-17, 1983.

SLAC-PUB-3281
EXCITATION OF SIMPLE ATOMS BY SLOW MAGNETIC MONOPOLES.
By Norman M. Kroll (UC, San Diego), Stephen Parke (Fermilab & SLAC), Venkatesh Ganapathi (UC, San Diego), S.D. Drell (SLAC), SLAC-PUB-3281, Jan 1984. 32pp.
Invited paper given at Monopole '83 Conf., Ann Arbor, MI, Oct 6-9, 183.

SLAC-TN-83-006
AN INTRODUCTION TO HIGH-ENERGY PHYSICS AND THE STANFORD LNEAR ACCELERATOR CENTER:SLAC.
By S.H. Clearwater (SLAC), SLAC-TN-83-006, Mar 1983. 11pp.

SLAC-TRANS-0206
ADJUSTMENT OF GEODETIC NETWORKS AT SLAC.
By Ingolf Burstedde, SLAC-TRANS-0206, Sep 1983. 49pp.
Translation of a German report.

SLAC-0266
SEARCH FOR CHARMED F MESONS IN e+ e- COLLISIONS WITH THE CRYSTAL BALL.
By R. Horisberger (SLAC), SLAC-0266, Jan 1984. 150pp.
Ph.D. Thesis.

SLAC/AP-010
COHERENT SYNCHRO - BETATRON OSCILLATIONS EXCITED BY THE BEAM-BEAM INTERACTION.
By Yukihide Kamiya, A.W. Chao (SLAC), SLAC/AP-010, Dec 1983. 22pp.

OTHER PUBLICATIONS BY SLAC AUTHORS

DESY-M-83-23
COMPARISON OF WAKE POTENTIAL CALCULATIONS IN TIME AND FREQUENCY DOMAINS.
By T. Weiland (DESY), K Bane, (SLAC), DESY-M-83-23, Aug 1983 4pp.
Presented at 12th Int. Conf. on High Energy Accelerators, Batavia, IL, Aug 11-16, 1983.

LBL-16217
CRYOGENIC TESTING OF THE TPC SUPERCONDUCTING SOLENOID.
By M.A. Green, R.G. Smits, J.D. Taylor, V. Van Slyke (LBL, Berkeley), F. Barrera, H. Petersen, C.E. Rago, R.I. Rinta, D. Talaska, R.D. Watt (SLAC), LBL-16217-mc (microfiche), Jun 1983. 82pp.

STANFORD LINEAR ACCELERATOR CENTER
MONTHLY REPORT FOR FEBRUARY 1984

I. ACCELERATOR AND RESEARCH OPERATIONS

A. OPERATING HOURS (Manned Hours)

Physics Beam Hours:[1] (Machine and Particle Physics) .... Total 618

Non-Physics Hours: Scheduled Downtime 8, Unscheduled Downtime 70. Total 78

TOTAL OPERATING HOURS 696

B. ELECTRON PULSES GENERATED

Total 1.5×10^8 Average 60 PPS

C. EXPERIMENTAL HOURS[2]

1. Particle Physics

EXPERIMENTAL AREA OR BEAMLINE[3]		EXPERIMENTAL TIME (Actual Hours)	TEST AND CHECKOUT HOURS	TOTAL EXPERIMENT HOURS
PEP				
	IR- 2			
	IR- 4	450		450
	IR- 6	450		450
	IR- 8	450		450
	IR-10			
	IR-12	450		450
SPEAR				
	EAST PIT			
	WEST PIT	532		532
ESA	3		349	349
ESB	19		72	72
	20		13	13
	14			
	8			
BSC	27			
	26/6			
TOTAL		2,332	434	2,766

2. Machine Physics

PEP 0, SPEAR 40, LINAC 127. 167

3. SSRL (Dedicated Time at SPEAR)[4] 20

TOTAL EXPERIMENTAL HOURS 2,953

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[1] Number of hours accelerator is run with one or more beams excluding accelerator beam tune-up and other non-physics beam time.

[2] Number of hours an experiment is run including actual beam hours and beam downtime "normal to the experiment."

[3] Refer to Figures 1 and 2 for beamline locations and experimental areas.

[4] Accelerator beam available to SPEAR storage ring.

D. OVERALL EXPERIMENTAL PROGRAM STATUS

1. Electronic Experiments

	Factored Hours*
Approved research hours at beginning of month	256
Hours run during the month	67
New hours approved during the month	---
Approved hours remaining at end of month:	189

2. PEP and SPEAR Experiments

	Actual Hours PEP	Actual Hours SPEAR
Approved research hours at beginning of month	---	1,791
Hours run during the month	1,860	532
New hours approved during the month	---	---
Approved hours remaining at end of month:	---	1,259

E. BEAM INTENSITY

Peak	65 mA
Average	4.46 μA

F. KLYSTRON EXPERIENCE

Total Klystron Hours	164,337
Number of Klystron Failures	4

G. DATA ANALYSIS

Bubble Chamber Events Measured	441

H. COMPUTER OPERATIONS (IBM 3081 K)

	Manned Hours
Computation Hours	
SLAC Facility Group	---
User Groups	670
Total Computation Hours:	670
Non-Computation Hours	
Scheduled Maintenance	16
Scheduled Modifications	---
Unscheduled Downtime and Reruns	10
Idle Time	---
Utility Failure	---
Total Non-Computation Hours:	26
TOTAL MANNED HOURS:	696

I. SPECIAL OPERATION FEATURES

The accelerator operated for 86 shifts at 60 pps during the month of February.

"Dedicated" and "Semi-dedicated" runs for the SLAC Linear Collider were made during operations on February 1, 2, 3 and 4, for a total of 9 shifts.

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* Factored hours are represented by the formula $T_c = T_0(R+20)/200$ where T_c = charged hours, T_0 = total hours beam was available to the experimenter for both check-out and data taking, and R = the average pulse repetition rate. Maximum for $(R+20)/200$ is 1.5 even if the calculated amount exceeds this value.

2. RESEARCH AREA AND EXPERIMENT STATUS

A. General

The accelerator operated the entire month in the non-SLED mode at 60 pps. *PEP* suffered more than the usual amount of hardware problems but managed to accumulate about 17 inverse picobarns for MARK II, MAC, HRS, and DELCO. During a ten hour downtime caused by an open magnet circuit, PEP-21 (Anomalous Single Photon) managed to install the second Pb-glass/PWC quadrant. Installation of the forward/backward veto counters will be attempted during a short shutdown in March.

In End Station A the 60 cm liquid hydrogen target was installed and operated for checkout of E-136 (e-p Elastic Scattering at High Q^2). At the end of the month checkout of that experiment was completed and the accelerator pulse repetition rate was raised to 120 pps for the March/April data taking.

At SPEAR, the MARK III detector (SP-32) operated the entire month.

After the first week of the month, the SLC Sector 10 testing was curtailed somewhat; so that two tests were completed in the positron beam and the hadron beam received pulses for SLD detector work. (L. Keller)

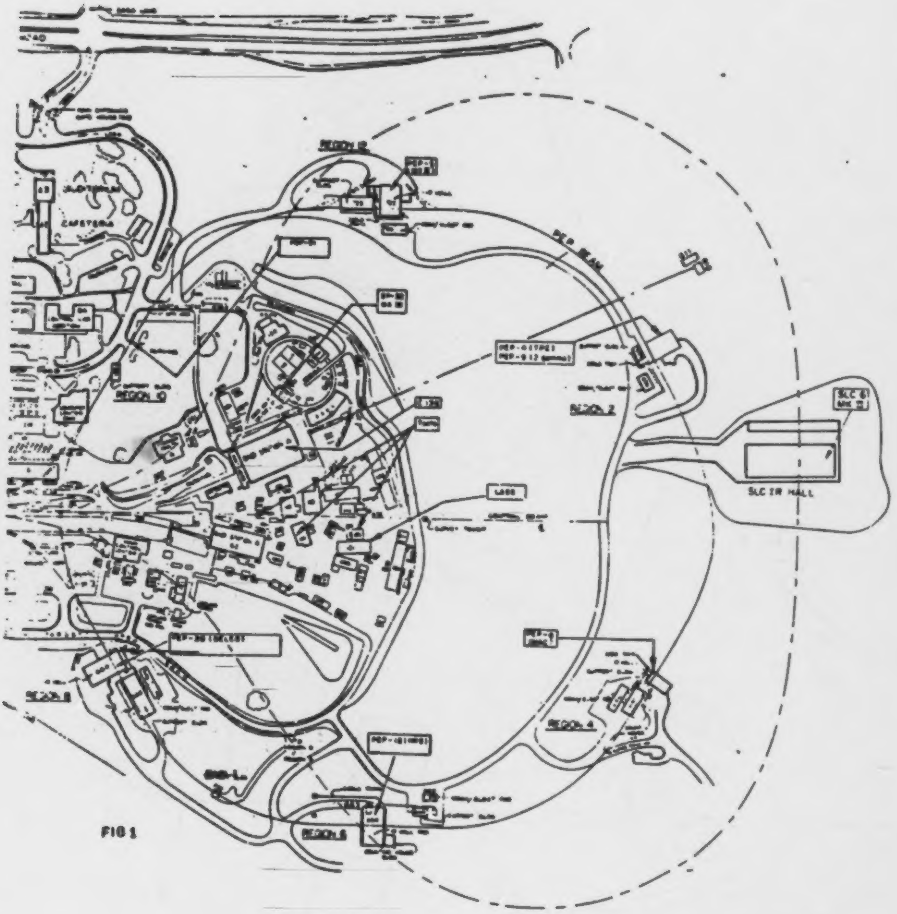
REGION 12
CAFETERIA
PEP BEAM
REGION 10
REGION 2
SLC &
MK II
SLC IR HALL
LASS
REGION 8
REGION 4
REGION 6

FIG 1

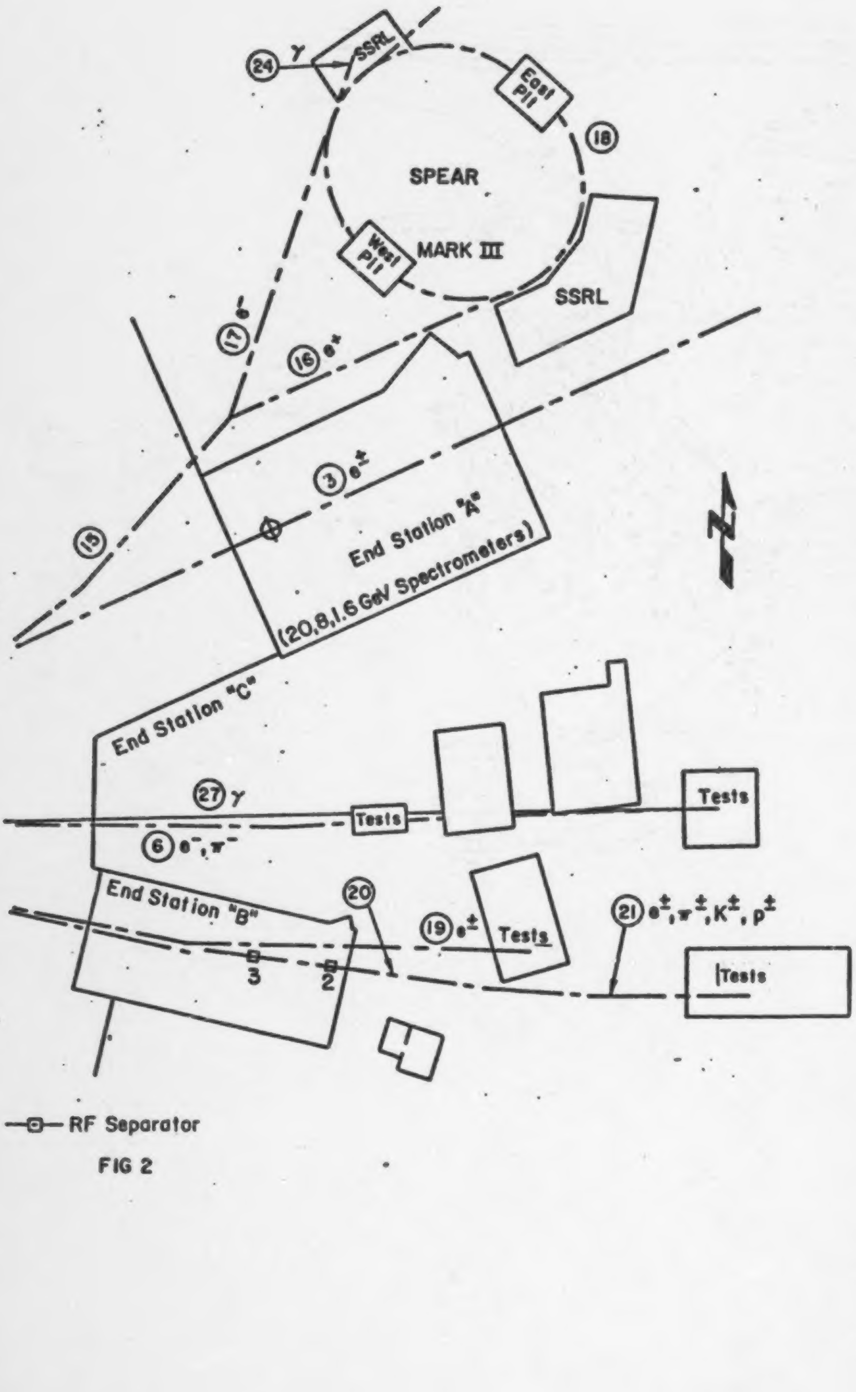
㉔ γ
SSRL
East Pit
⑱
SPEAR
West Pit
MARK III
SSRL
⑰ e⁻
⑯ e⁺
③ e±
⑬
End Station "A"
(20,8,1.6 GeV Spectrometers)
End Station "C"
㉗ γ
Tests
Tests
⑥ e⁻, π⁻
End Station "B"
⑳
⑲ e±
Tests
㉑ e±, π±, K±, p±
Tests
3
2
N
RF Separator

FIG 2

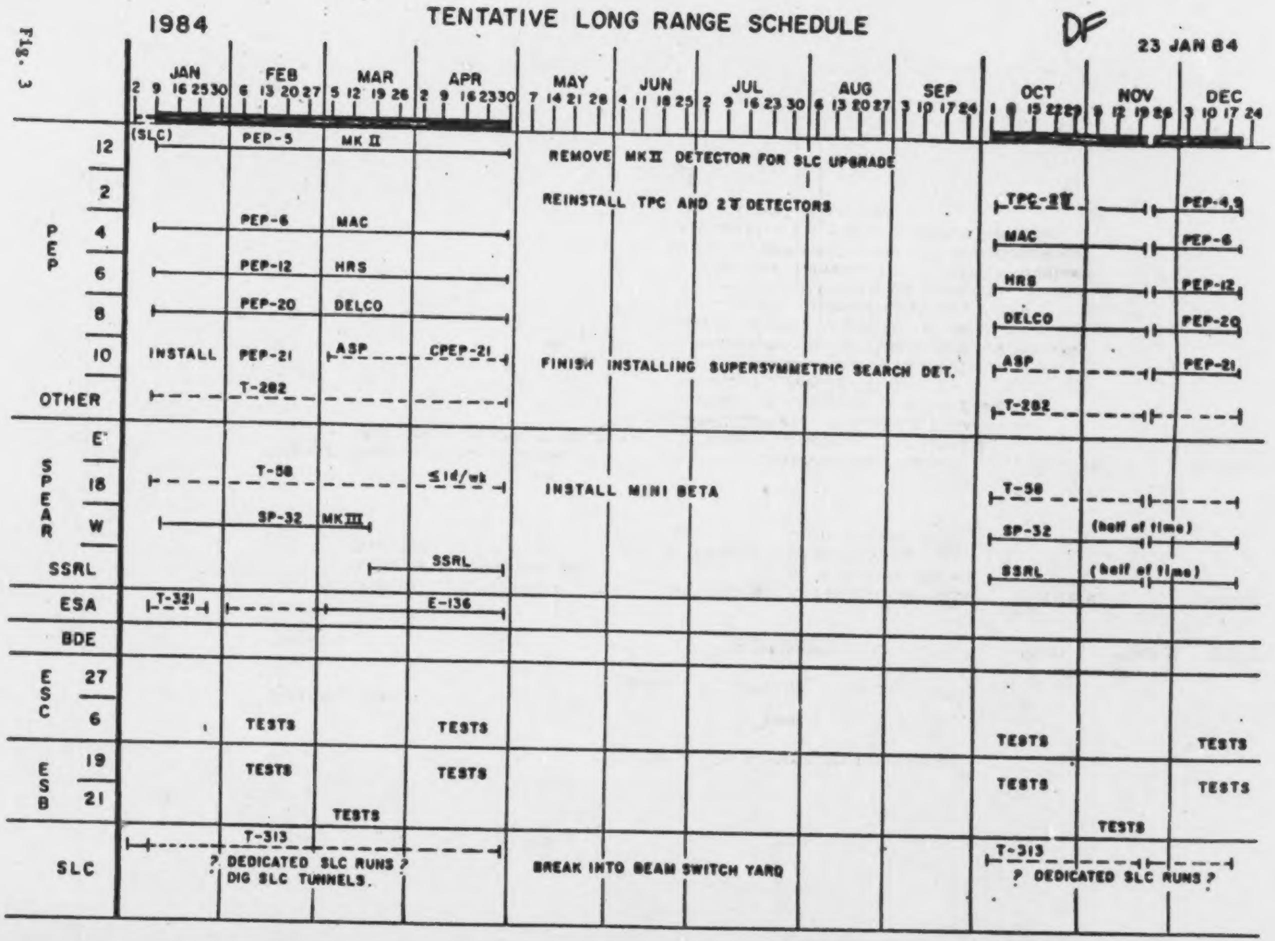
1984
TENTATIVE LONG RANGE SCHEDULE
DF
23 JAN 84
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2 9 16 25 30 6 13 20 27 5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 3 10 17 24
PEP
12
2
4
6
8
10
OTHER
SPEAR
E
18
W
SSRL
ESA
BDE
ESC
27
6
ESB
19
21
SLC
(SLC)
PEP-5
MK II
REMOVE MK II DETECTOR FOR SLC UPGRADE
REINSTALL TPC AND 2γ DETECTORS
TPC-2γ
PEP-4,9
PEP-6
MAC
PEP-12
HRS
PEP-20
DELCO
INSTALL
PEP-21
ASP
CPEP-21
FINISH INSTALLING SUPERSYMMETRIC SEARCH DET.
T-282
T-58
≤1d/wk
INSTALL MINI BETA
SP-32
MK III
(half of time)
SSRL
T-321
E-136
TESTS
T-313
? DEDICATED SLC RUNS ?
DIG SLC TUNNELS.
BREAK INTO BEAM SWITCH YARD

Fig. 3

STANFORD LINEAR ACCELERATOR CENTER

TABLE 1

February, 1984

TABLE OF APPROVED EXPERIMENTS

Number	Title	Experimenters	Date Approved Stage 1	Date Approved Stage 2	Status
E-136	Elastic Electron-Proton Cross Sections at High Momentum Transfer	AMERICAN U.: R. ARNOLD, P. Bosted, S. Rock, Z.M. Szalata U. BONN: B. A. Mecking SLAC: D. J. Sherden	5/16/81		Checkout
SP-32	Studies of the Weak Decays of D Mesons at the ψ'' Resonance	C.I.T.: R.Baltrusaitis, J.Hauser, D. HITLIN, J.Richman, J.J.Russell SLAC: K.Bunnell, D.Coward, K.Einsweiler, D.Hutchinson, R.Mozley, A.Odian, J.Roehrig, W.Toki, Y. Unno, F. Villa UCSC: H.Bledsoe, D.Dorfan, R.Fabrizio, F.Grancagnolo, R.Hamilton, C.Heusch, T.Schalk, H.Sadrozinski, A. Seiden, D. Smith U. ILLINOIS: J.Becker, R.Cassell, H.Cui, B.Eisenstein, G.Gladding, S.Plaetzer, A.Spadafora, J.Thaler, A.Wattenberg, W.Wisniewski U. WASH.: J.Brown, T.Burnett, V.Cook, C.delPapa, H.Lubatti, K.Moriyasu, J.Rothberg, J.Sleeman, H. Willutski, D. Wisinski	5/16/81		Running

February, 1984 Table of Approval Experiments (continued) - 2

Number	Title	Experimenters	Date Approved	Status
PEP-4 (TPC)	A PEP Facility Based on the Time Projection Chamber	LBL: M.Alston-Garnjost, A.Barbaro-Galtieri, A.Barnes, A.Bross, W.C. Carithers, O.Chamberlain, A.Clark, O.Dahl, C.Day, P.Eberhard, D.Fancher, R.Kenney, L.Kerth, S.Loken, G.Lynch, M.Madaras, R.Majka, P.Martin, J.Marx, P.Nemethy, D.Nygren, P.Oddone, M.Pripstein, P.Robrish, M.Ronan, R. Ross, G.Shapiro, M.Stevenson, W.Wenzel UCLA: C.Buchanan, J.Hauptman, D.Stork, W.Slater, H.Ticho YALE: M.Zeller UCR: W.Gorn, J. Layter, B. SHEN, G.VanDalen JOHNS-HOPKINS: B. Barnett B.Blumenfeld, C.-Y.Chien, L.Madansky, J. Matthews, A. Pevsner U. TOKYO: J.Chiba, H.Fujii, T. Fujii, T.Kamae	21 Jan. 1977	Upgrading
PEP-5 (MK II)	General Survey of Particle Production at PEP	SLAC: A.Boyarski, M.Breidenbach, D.Burke B.Delcourt, J. Dorenbosch, J.Dorfan, G.Feldman, G.Hanson, R. Hollebeek, W.Innes, J.Jaros, R.R.Larsen, B.Loehr, N. LOCKYER, V. Luth, M.Perl, B.Richter, A. Roussarie, D.Scharre, J.Siegrist, R.Vidal, J. Weiss LBL: G.Abrams, A.Blondel, W.Chinowsky, G.Gidal, G.Goldhaber, A.Johnson, J. Kadyk, A.Lankford, J.Strait, G.Trilling, I.Videau, Y.Wang, G.Zhao HARVARD: A.Baecker, C.Blocker, R. Schwitters	1/21/77	Running
PEP-6 (MAC)	A Lepton Total Energy Detector	U.COLORADO: W. Ford, J. Smith U.WISCONSIN: J.Johnson, R. Morse, R.Prepost, D. Wiser SLAC: W. Ash, G.Chadwick, P.Leung, S.Michalowski, D. Ritson U.UTAH: D.Groom, E. Loh NORTHEASTERN U; L.Baksay, H.Band, W.Faissler, M.Gettner, B.Gottschalk, J.Morimisato, D.Shambroom, E.VonGoeler, R. WEINSTEIN	1/21/77	Running

Number	Title	Experimenters	Date Approved	Status
PEP-9 (2-Gamma)	PEP Forward Detector Facility	UCD: W. Ko, R.LANDER, D.Pellett, C. Williams UCSD: G.Masek, E.Miller, W.Vernon UCSB: V.Bharadwaj, D.Caldwell, A.Eisner, A.Lu, R. Morrison, S. Yellin NIKHEF: J.Armitage, F.Erne, W.Langefeld, H.Paar, H.Sens, J.Timmer	21 Jan. 1977	Upgrading
PEP-12 (HRS)	High Resolution Spectrometer	ANL: M.DERRICK, E.Fernandez, L.Hyman, R.Klem, P.Kooijman, S.Kooijman, J.Loos, L.Price INDIANA U.: G.Baranko, B.Brabson, G.Forden, S.Grey, J.-P.Guillaud, D.Koltick, H.Neal, H. Ogren, D. Rust U. MICHIGAN: C.Akerlof, J.Chapman, N.Harnew, D. MEYER, D.Nitz, D.Rubin, A.Seidl, R.Thun PURDUE: R.DeBonte, R.Jones, F.Loeffler, R. McIlwain, D.Miller, P.Ong, L.K.Rangan, E. Shibata, R.Stevens, B.Wilson, D.Wood LBL: B. Cork SLAC: L. Keller, J. Va'vra	29 Jan. 1978	Running
PEP-20	DELCO at PEP	CIT: B.Barish, S.-C. Gao, Y.-Z. Huang D.Koop, J.Ludwig, G.Mills, S.Sherman, R. Stroynowski, H. Yamamoto, SLAC: W.Atwood, P.Baillon, H.DeStaebler, H.Kichimi, A. Ogawa, D.Perret-Gallix, R.Pitthan, C.Prescott, L.Rochester, R. Taylor, S.-Q.Wang, C.Young STANFORD U: G./Bonneaud, G.Donaldson, M.Duro, G.Irwin, J.KIRKBY, D. Pollard, S. Wojcicki, W.-G. Yan	9/8/78	Running
PEP-21	Search for Unseen States Using Photon Tagging	SLAC: D.BURKE, R.HOLLEBEEK, M.Jonker MIT: S. Whitaker U.WASH: R.Davisson, J.Rothberg, K.Young SUNY-STONY BROOK: P.Grannis	5/14/83	Planning/Setup
SLC-6	MARK II at the SLC	SLAC: D.DURFAN, G.FELDMAN U. MICHIGAN LBL: G. TRILLING C.I.T., UC-SantaCruz, U.Hawaii	5/14/83	Planning

February, 1984 Table of Approval Experiments (continued) - 4

Number	Title	Experimenters		Date Approved	Status
D-24	SSRL Dedicated Time	SLAC/SSRL:	H. Winick	12/04/75	Planning
D-28	Resonance Radiation	STANFORD:	H. Piestrup	9/19/80	Planning
D-30	Channeling Radiation	SUNY-ALBANY	C.R. Sun	10/8/82	Planning
P-0	Operator Training	SLAC:	D. Tsang		Planning
P-1	Beam Dynamics Tests for the SLC	SLAC:	G.Loew, R.Miller, R.Stiening		Inactive
P-6	General Equipment Checkout	SLAC:	G. Loew		Test
P-7	Positron Source Tuneup	SLAC:	G. Loew, R.Miller	10/01/71	Test
P-9	SPEAR Tuning Test	SLAC:	G. Loew		Test
T-58	SPEAR Electron Storage Ring Tests	SLAC:	B.Richter, J.Rees, J.Harris	11/21/71	Running
T-172	Beam Line 6 Checkout	SLAC:	R. Gearhart	10/24/74	Inactive
T-276	Beam Line 27	SLAC:	J. Murray	11/15/79	Inactive
T-282	PEP Accelerator Studies	SLAC:	E. Paterson	1/18/80	Planning
T-296	19 Line Setup and Checkout	SLAC:	T. Fieguth	10/22/80	Inactive
T-298	PEP-12 Wire Calorimeter Test	ANL:	L. Price	10/27/80	Inactive
T-300	Cerenkov Ring Imaging Detector	SLAC:	S. Williams	1/13/81	Running

Number	Title	Experimenters		Date Approved	Status
T-313	SLC Damping Ring Checkout	SLAC:	S. Ecklund	12/22/81	Running
T-319	CCD Development	SLAC:	S. Shapiro	4/16/82	Running
T-321	Section 10 Profile Monitors	SLAC:	V. Luth	5/10/82	Planning
T-328	Test of Cerenkov Counters for $e^{\pm}$ Identification	U. WASH.	V. Chaloupka	12/21/82	Inactive
T-338	MARK II/SLC Drift Chamber	SLAC:	A. Boyarski	5/19/83	Planning
T-344	Test of Lead Glass	KEK: SLAC:	K. Ogawa R. Gearhart	9/26/83	Running
T-346	Test B/L 20/21 at Low Momenta	SLAC:	R. Gearhart S. Shapiro	11/9/83	Planning
T-348	SLD Drift Chamber Tests	SLAC:	C. Prescott	11/29/83	Planning
T-349	SLC Calorimeter Tests	U. WASH. U. WISC.	P. Mockett J. Johnson	11/17/83	Planning
T-351	Energy Calibration for E-137	VPI:	L. Mo	12/16/83	Running/Comp.
T-352	Lead-Lucite Shower Counter Test	PRINCETON:	G. Gollin	1/26/84	Planning

STATUS:
Running = Experiment is in data collection phase and was a prime user of accelerator time.
Checkout = Experiment is in checkout phase and used accelerator time for checkout purposes.
Setup = Experiment was being setup in the research yard, or PEP I.R.
Inactive = Experiment was inactive in the research yard.
Construction = Experiment and/or beam is under construction.
Ready to Run = Experiment ready for future scheduled run.
Parasiting = Used parasite beam time.
Complete = Experiment completed.
Test = Test run performed.
Planning = In design & planning stage.
Upgrading = Experimental equipment is being upgraded.
Repair = Down for Equipment Repair

3. ACCELERATOR IMPROVEMENTS

A. Nuclear Physics Injector

The design work for both mechanical and electronic assemblies is continuing. An on-site inspection of the injector area in the tunnel was made by the project team during a shutdown of the linac. Pictures of the accelerator section were made and decisions regarding the exact placement of each component were agreed upon. The model #7 gun has been assembled and has completed the bakeout process; beam testing will take place next. Fabrication has begun for the bucking coil, alpha magnet support stand, and the compensator core. (G. Loew)

4. RESEARCH DIVISION DEVELOPMENTS

A. Data Analysis Group Activity

Hardware: The VAX-11/750 computer received last month for use by the PEP-21 experiment as a data acquisition system was installed, and the 750 borrowed from the Dutch collaboration in PEP-9 was returned.

The 780 computer used for development of the SLC instrumentation and control system was moved from the Central Lab to MCC.

An 0.8-Gbyte shared disk system from System Industries was installed at the PEP-9 VAX complex in IR-2.

Work was started on developing a surveying device for measuring transverse dimensions on an SLC achromatic magnet assembly. Effort so far has focused on trying to define a straight line (1:3000000 horizontally) by pulling 200 feet of 2-pound test line off a spinning reel and stretching it taut.

Software: Work was started on installing Xerox Network Services protocols on the 3081. We have bought this software, ready to go, for VAXes and are now trying to migrate it to VM. It will form the basis for a file transfer package once it is up and running.

Operations: During February 444 events were measured in 166 hours and 64,192 frames scanned in 487 hours.

The total scanner headcount remained at 5.6 full time equivalent persons. (J. Brown)

5. PEP DEVELOPMENTS

A. PEP Activities

PEP ran throughout February with steadily improving performance. The peak luminosity exceeded 2×10^{31} cm^{-2}sec^{-1} for the first time this operating cycle but the integrated luminosity was hurt by several hardware problems which caused 20% downtime. These problems were distributed through many systems and were all corrected by the end of the month. Even with this above average downtime the integrated luminosity was almost 17 inverse picobarns. (E. Paterson)

	Hours	% of Scheduled Operating Time
Scheduled Downtime	64	
Scheduled Operating Time	632	
Hours This Month	696	
Ring Downtime	128	20
Linac Downtime	54	9
Colliding Beams and Fill/Tune	449	71
Experimenter Access	1	- -

6. PUBLICATIONS ISSUED

SLAC-PUB-3169 Rev.
A 650-mm LONG LIQUID HYDROGEN TARGET FOR USE IN A HIGH INTENSITY ELECTRON BEAM.
By J. Mark (SLAC), SLAC-PUB-3169 Rev., Feb 1984. 7pp.
Revised version.
Contributed to Cryogenic Engineering Conf., and Int. Cryogenic.Materials Conf., Colorado Springs, CO, Aug 11-19, 1983 .

SLAC-PUB-3191
NUCLEAR CHROMODYNAMICS: IMPLICATIONS OF QCD FOR NUCLEAR PHYSICS.
By Stanley J. Brodsky (SLAC), SLAC-PUB-3191, 1983. 76pp.
Published in Short-Distance Phenomena in Nuclear Physics, ed. David H. Boal, Richard M. Woloshyn, New York Plenum,p.141-217, 1983.

SLAC-PUB-3199
THE CENTRAL DRIFT CHAMBER FOR THE MARK-III DETECTOR AT SPEAR.
By J. Roehrig, K. Einsweiler, D. Hutchinson, E. McNerney, A. Odian, K. Skarpaas, Y. Unno, F. Villa (SLAC), F. Grancagnolo, W. Rowe, A. Seiden (UC, Santa Cruz), R.M. Baltrusaitis, J. Hauser, J. Richman, J.J. Russell (Cal Tech), G. Blaylock, J. Thaler, W. Wisniewski (Illinois U., Urbana), SLAC-PUB-3199, Aug 1983. 40pp.

SLAC-PUB-3205
PION PAIR PRODUCTION FROM gamma gamma COLLISIONS AT PEP.
By J.R. Smith, D.L. Burke, G.S. Abrams, D. Amidei, C.A. Blocker, Adam M. Boyarski, Martin Breidenbach, William Chinowsky, W.E. Dieterle, J.B. Dillon, J. Dorfan, M.W. Eaton, G.J. Feldman, M.E.B. Franklin, G. Gidal, L. Gladney, M.S. Gold, Gerson Goldhaber, L. Golding, G. Hanson, R.J. Hollebeek, W.R. Innes, J. Jaros, Alfred D. Johnson, J.A. Kadyk, A.J. Lankford, Rudolf R. Larsen, B. LeClaire, M.E. Levi, N. Lockyer, V. Luth, C. Matteuzzi, M.E. Nelson, J.F. Patrick, Martin L. Perl, Burton Richter, P.C. Rowson, T. Schaad, H. Schellman, D. Schlatter, R. Schwitters, P.D. Sheldon, J. Strait, C. de la Vaissiere, J. Weiss, J.M. Yelton, C. Zaiser (SLAC & LBL, Berkeley & UC, Berkeley & Harvard U.), SLAC-PUB-3205, Sep 1983. 30pp.

SLAC-PUB-3221
ELEMENTARY PRINCIPLES OF LINEAR ACCELERATORS.
By G.A. Loew (SLAC), R. Talman (Cornell U., LNS), SLAC-PUB-3221, Sep 1983. 91pp.
Presented at 2nd Summer School on High Energy Particle Accelerators, Stanford, CA, Aug 2-13, 1982.

SLAC-PUB-3272
ON THE INTERACTION OF FERMIONS WITH A FINITE-SIZED, NON-ABELIAN MONOPOLE.
By William Goldstein (SLAC), SLAC-PUB-3272, Dec 1983. 32pp.

SLAC-PUB-3273
ASPECTS OF THE DYNAMICS OF HEAVY QUARK SYSTEMS.
By Michael E. Peskin (SLAC), SLAC-PUB-3273, Dec 1983. 79pp.
Presented at 11th Int. SLAC Summer Inst. on Particle Physics, Stanford, CA, Jul 18-26, 1983.

SLAC-PUB-3274
A MEASUREMENT OF THE D0 LIFETIME.
By J.M. Yelton, L. Gladney, Gerson Goldhaber, G.S. Abrams, D. Amidei, A.R. Baden, Adam M. Boyarski, J. Boyer, Martin Breidenbach, P. Burchat, F. Butler, D.L. Burke, J. Dorfan, G.J. Feldman, G. Gidal, M.S. Gold, L. Golding, G. Hanson, D. Herrup, R.J. Hollebeek, W.R. Innes, J. Jaros, I. Juricic, J.A. Kadyk, A.J. Lankford, Rudolf R. Larsen, B. LeClaire, M.E. Levi, N. Lockyer, V. Luth, C. Matteuzzi, M.E. Nelson, R.A. Ong, Martin L. Perl, Burton Richter, M.C. Ross, P.C. Rowson, T. Schaad, N. Schellman, D. Schlatter, W.B. Schmidke, P.D. Sheldon, G. Trilling, C. de la Vaissiere, D.R. Wood, C. Zaiser (SLAC & LBL, Berkeley & UC, Berkeley & Harvard U.), SLAC-PUB-3274, Feb 1984. 11pp.

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A PARTICIPATOR: THE METAPHYSICAL SUBJECT.
By Christopher Gefwert (Helsinki U. & SLAC), SLAC-PUB-3277, Dec 1983. 56pp.

SLAC-PUB-3280
NONLINEAR REALIZATIONS AND THE PARTIAL BREAKING OF EXTENDED SUPERSYMMETRY.
By Jonathan Bagger (SLAC), SLAC-PUB-3280, Jan 1984. 22pp.
Presented at Workshop on Supersymmetry in Physics, Los Alamos, N. Mex., Dec 14-21, 1983.

SLAC-PUB-3282
ECONOMIC ASPECTS OF HEAVY ION FUSION.
By W.B. Herrmannsfeldt (SLAC), SLAC-PUB-3282, Jan 1984. 15pp.
Presented at Heavy Ion Fusion Workshop, Tokyo, Japan, Jan 23-26, 1984.

SLAC-PUB-3288
PARTICLE SUBSTRUCTURE: A COMMON THEME OF DISCOVERY IN THIS CENTURY.
By W.K.H. Panofsky (SLAC), SLAC-PUB-3288, Feb 1984. 44pp.
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Published in Published in Contemporary Physics, Vol.23, p.24-44 (1982).

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AN UPPER LIMIT ON THE tau-neutrino MASS.
By C. Matteuzzi, G.S. Abrams, C. de la Vaissiere, D. Amidei, A.R. Baden, Adam M. Boyarski, J. Boyer, Martin Breidenbach, P. Burchat, F. Butler, D.L. Burke, J. Dorfan, G.J. Feldman, G. Gidal, L. Gladney, M.S. Gold, Gerson Goldhaber, L. Golding, G. Hanson, D. Herrup, R.J. Hollebeek, W.R. Innes, J. Jaros, I. Juricic, J.A. Kadyk, A.J. Lankford, Rudolf R. Larsen, B. LeClaire, M.E. Levi, N. Lockyer, V. Luth, M.E. Nelson, R.A. Ong, Martin L. Perl, Burton Richter, M.C. Ross, P.C. Rowson, T. Schaad, H. Schellman, D. Schlatter, P.D. Sheldon, W.B. Schmidke, G. Trilling, D.R. Wood, J.M. Yelton, C. Zaiser (SLAC & LBL, Berkeley & UC, Berkeley & Harvard U.), SLAC-PUB-3291, Feb 1984. 9pp.

SLAC-TN-84-001
TIME DOMAIN REFLECTOMETRY FOR SLC BPM SYSTEM.
By D.R. Thompson (SLAC), SLAC-TN-84-001, Jan 1984. 23pp.

SLAC-TRANS-0207
THEORETICAL GEOMETRY OF THE LEP.
By M. Mayoud, SLAC-TRANS-0207, Nov 1983. 28pp.
Translated from report, CERN-LEP-SU/MM/138/SB, Jun 1983(translation).

SLAC-TRANS-0208
THREE-DIMENSIONAL COORDINATE SYSTEM USED AT CERN.
By J. Gervaise, M. Mayoud, E. Menant, SLAC-TRANS-0208, Nov 1983. 29pp.
Translated from report, CERN-76-03, Feb 1976(translation).

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By M. Mayoud, E. Menant, SLAC-TRANS-0209, Nov 1983. 12pp.
Translated from French report, CERN-SSP/SU/MM/EM/SG, dated Feb 1976(translation).

SLAC/AP-0011
THE SECOND ORDER PARTICLE MOTION EQUTIONS AND LINEAR CHROMATICITY CALCULATION IN ACCELERATOR RINGS.
By R.Z. Liu (SLAC & Stanford U., SSRL), SLAC/AP-0011, Jan 1984. 47pp.

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TECHNIQUES IN MACHINE FUNCTION INTEGRAL CALCULATION.
By R.Z. Liu (SLAC & Stanford U., SSRL), SLAC/AP-0012, Jan 1984. 28pp.

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DISPERSION FUNCTION AND CLOSED ORBIT DISTORTION IN ACCELERATOR RINGS.
By R.Z. Liu (SLAC & Stanford U., SSRL), SLAC/AP-0014, Feb 1984. 27pp.

OTHER PUBLICATIONS, BASED UPON RESULTS OF SLAC RESEARCH

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CHARGED HADRON PRODUCTION IN e+ e- ANNIHILATION AT 29-GeV.
By TPC Collaboratio (LBL, Berkeley & UCLA & UC, Riverside & Johns Hopkins U. & Massachusetts U., Amherst & Tokyo U. & Yale U.), LBL-17142, Dec 1983. 17pp.

LNF-83/76-P
MEASUREMENT OF THE b LIFETIME WITH MAC.
By I. Peruzzi (Frascati), LNF-83/76-P, Nov 1983. 7pp.
Invited talk given at Workshop 'Search for Heavy Flavors', Como, Italy, Aug 29-30, 1983.

3.1 Fixed-Target Program

1. **What new science is being explored by this program? What scientific opportunities are being exploited?**

   Answer: The linear accelerator remains the highest energy and intensity electron accelerator in the world. Beams used for fixed-target physics include electrons, positrons, photons, longitudinally polarized electrons, transverse, and circularly polarized photons, muons, and neutral-kaons. The fixed-target program at this time features a precise measurement of elastic electron-proton scattering at large momentum transfer values and a series of experiments to study the structure of very light nuclei. The main priority at SLAC is given to the e+e- colliding-beams research programs, and as a consequence the scale of the fixed-target program is substantially reduced compared to previous years.

2. **What types of research instrumentation/experimental devices are available for this program, and what are their capabilities?**

   Answer: The experimental devices and facilities available for fixed-target physics at the Stanford Linear Accelerator Center include a hybrid bubble chamber facility (a combination of a small rapid cycling bubble chamber and an array of electronic detectors) for photon physics experiments, the LASS spectrometer with superconducting solenoid magnet for hadron physics experiments, and three large magnetic spectrometer systems in End Station A for electron scattering experiments.

3. **What have been the program's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

   Answer: The following examples, taken from the material provided in response to question 3.0.1, illustrate some of the more important experimental results that have been obtained since 1981 in the SLAC fixed-target research program.

1. Charmed Particle Lifetime

Five kinds of quarks are presently known. The fourth of these is called the "charmed" quark. The combination of a charmed quark with a different kind of antiquark (or vice versa) produce a particle called a charmed meson. Measuring how long this meson exists before it decays into other particles provides an indirect measurement of the lifetime of its constituent charmed quark to change to a strange quark. The measured lifetime is less than a millionth of a second, and the measurement of so short a lifetime required the use of an exceptionally clever technique. An experiment was carried out in a specially adapted bubble chamber, where the particles were created in the chamber by a beam of high energy gamma rays produced by back scattering of a laser beam from an electron beam from the SLAC two mile linear electron accelerator. This experiment made use of a special camera added to the bubble chamber that was able to resolve particle tracks with a resolution of 55 micrometers, and was thus actually able to photograph the track of the charmed particle before it decayed.

2. The EMC Effect

Some time ago the European Muon Collaboration (EMC), a group working at the CERN lab in Geneva, reported a result that has stimulated both a review of old work and some new experimental work at SLAC. Briefly, the two groups agree that beams of electrons (SLAC) or of the "heavy electrons" called muons (CERN) used in scattering experiments produce results that depend upon the kind of target that is used. For example, the nucleus of a deuterium atom contains two nucleons (one proton plus one neutron), while the nucleus of an iron atom contains fifty-six nucleons, and the assumption was that the electrons or muons would scatter off the quarks that constitute these nucleons in a manner that did not depend upon how many nucleons were grouped together within a nucleus. But this turned out not to be the case. For the heavier nuclei, there seem to be more quarks that have low momentum, and fewer quarks that have high momentum. One of the possible explanations of this result is that quarks may not be bound as tightly and as permanently within the confines of a single nucleus as had been thought, but may wander between individual nucleons. It also may be that larger "bags" of quarks are possible than the usual three to a bag.

4. For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the program. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: A rough estimate of the operating and equipment funds which can be attributed to the fixed-target program at SLAC are given in the table below. It must be recognized that neither SLAC nor DOE maintains accounting records in a fashion that allows the direct determination of the total resources expended on a particular sub-parts of the SLAC facility or experimental program.

Operating & Equipment Funds
(Budget Authority in thousands)

	Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$13,821	$11,330	$12,759	$14,510	$ 7,292
In-House Research	2,040	1,958	1,979	2,300	1,576
Operations	10,241	8,462	9,400	10,932	5,006
Other Operating Expenses	1,540	910	1,380	1,278	710
Equipment	591	663	734	220	217
Construction	1013	1621	2240	2194	2391
Accelerator Improvements*	1001	1343	2000	1900	2265
General Plant Projects	12	278	240	294	126
Total Funding	$15,425	$13,614	$15,733	$16,924	$ 9,900

* AIP funds for linac energy upgrade and control improvements are important for both the linac fixed-target program and for the SLC.

5. **How much of the program's for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

Answer: The Stanford Linear Accelerator Center (SLAC) fixed-target program receives no direct funding from any other Federal agency, nor any State agency. However, some of the university based users who perform fixed-target experiments at SLAC receive their direct research support via NSF grants.

6. **For the period FY 1981 operation) - FY 1985, please provide actual and estimated staffing levels for the program.**

Answer: A rough estimate of the manpower devoted to the fixed-target program operations including scientists analyzing and interpreting data recorded in the experiments is given in the table below. It must be recognized that neither SLAC nor DOE maintains records in a fashion that allows the direct determination of the total manpower devoted to a particular subpart of the SLAC facility or experimental program.

Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
285	219	226	247	89

7. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

Answer: Full utilization of the Stanford Linear Accelerator Center fixed-target facility would be defined as 830 eight-hour shifts per year at a pulse repetition rate of 360 pulses/sec. Pulse utilization is the important parameter for fixed-target and hadron scattering experiments and this is shown for the period FY 1981 - FY 1985 in the following table:

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Pulse Utilization (%)	25	20	27	15	18

8. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer: The information requested is as follows:

Fixed-Target Experiments Started, Running, and Completed by Year for FY 1981 - FY 1985

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Started	0	1	2	0	1
Running	3	4	5	2	1
Completed	0	1	3	2	0

9. How many research proposals have been submitted over the past five years (or since the beginning of operation if later), and how many of these have been approved?

Answer: Proposals submitted to Stanford Linear Accelerator Center for fixed-target experiments and those approved by calendar year for 1979 - 1983, follow:

	1979		1980		1981		1982		1983	
	SUB	APP	SUB	APP	SUB	APP	SUB	APP	SUB	APP
Fixed Target	6	4	2	1	0	1*	1	0	1	1

* E-136 approved in 1981, was submitted in 1980.

10. How many university personnel (i.e., faculty and students) have participated in the program over the past five years?

Answer: Two hundred seventeen university personnel (faculty and students) have participated in the program over the past five years. Of these, 86 were users of the test beam facilities only.

11. How many industrial researchers have participated in the program over the past five years?

Answer: There have been no industrial researchers participating in the fixed-target program at the Stanford Linear Accelerator Center in the past five years.

12. How many researchers from foreign institutions have participated in the program over the past five years?

Answer: Ninety-six researchers from foreign institutions have participated in the program over the past five years. Of these, 18 were users of the test beam facilities only.

13. What are the future possibilities for this program (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: After completion of the energy upgrade of the linear accelerator to 50 GeV, it will be possible to do fixed-target experiments in the new domain opened up by the availability of high intensity beams of 50 GeV electrons and positrons. No firm plans for such a program of fixed-target experiments have been developed to date.

3.2 Stanford Positron-Electron Asymmetric Ring (SPEAR)

1. **What new science is being explored by SPEAR? What scientific opportunities are being exploited?**

Answer: The following two examples illustrate the science being explored and the scientific opportunities being exploited at SPEAR.

1. "Charmonium" Spectrum

Physicists are particularly interested in simple systems of particles that can exist in many different energy states. An example is the hydrogen atom, which consists of one electron and one proton bound together by the force of electromagnetism, and which can exist in many different "excited" states. An even simpler example is the "atom" called "positronium", which consists of an electron bound together with its antimatter counterpart, a positron. The whole series of states in which such combinations can exist is called its spectrum, and the study of such states is called spectroscopy.

The combination of a charmed quark and a charmed antiquark is a similar system called "charmonium", and studies of charmonium spectroscopy have been important at SLAC ever since the original discovery of this system in 1974. In recent years, there have been two very important sets of experiments that have dealt with this area. First, a special detection system designed to detect energetic photons (the Crystal Ball) made a detailed study of all the states of charmonium that could be reached by having a higher energy state emit a photon and drop down to a lower energy state. This led to the discoveries of two important states (eta-c and eta-prime-c) that confirmed the spectrum and its similarity to the analogous spectrum of positronium.

2. Particles Consisting of Gluons?

The strong force that binds quarks together inside hadrons is believed to be carried by particles called gluons. According to the well-regarded theory that describes this force (quantum chromodynamics, or QCD), it should be possible for two or more gluons themselves to stick together to form discrete particles. Both the Crystal Ball and the Mark III detectors working at SPEAR have uncovered evidence for states that are candidates for "glueballs". The Mark III is continuing the study of these and other states that are observed when the psi particles (charmed quark-antiquark combinations) decay into other particles by emitting a photon. One new state that has been discovered in this work does not yet have a satisfactory explanation in terms of known phenomena.

2. **How does SPEAR's performance compare with any other storage rings in the world that are operating, under construction, or planned?**

Answer: The SPEAR storage ring operates 50 percent of the time for high energy physics and 50 percent of the time as a dedicated synchrotron radiation source. In the high energy physics mode, it is operated normally at energies between 3 and 6 GeV in the center-of-mass with the luminosity increasing from 10^{30} to 10^{31} cm^{-2} sec^{-1} through this energy range. A luminosity upgrade program which is under way this year will increase this by a factor of four to five. This energy and luminosity are unique in the world today in the study of the physics of the charmed quark. The higher energy rings in the U.S., i.e., Cornell Electron Storage Ring (CESR) (8 GeV x 8 GeV) and the Positron-Electron Project (15 GeV x 15 GeV) (PEP), can not operate effectively at these lower energies, nor can the 22 GeV e+e- Petra ring at Hamburg, and the DORIS II ring in Hamburg is now optimized for studies at 10 GeV (5 GeV x 5 GeV) in the center-of-mass. Three other e+e- colliding beams storage rings are currently under construction: the 60 GeV x 60 GeV LEP ring at CERN, the 30 GeV x 30 GeV Tristan ring in Japan, and the 2.2 GeV x 2.2 GeV in Peking. These are expected to be in operation in 1989, 1988 and 1987 respectively. The VEP-IV ring in Novosibirsk at a design energy of 7 GeV x 7 GeV, first operated in 1979.

As a dedicated synchrotron light source, SPEAR is presently the most productive source of synchrotron radiation in the world, using the technology of beam wigglers and undulators. An ongoing development program will lower the beam emittance and increase the brightness of the synchrotron radiation sources.

3. **What types of research instrumentation/experimental devices are available at SPEAR, and what are their capabilities?**

Answer: SPEAR has two interaction regions. The Mark III detector presently occupies the west region. The properties of the Mark III are described in Attachment A. There is presently no detector in the second interaction region.

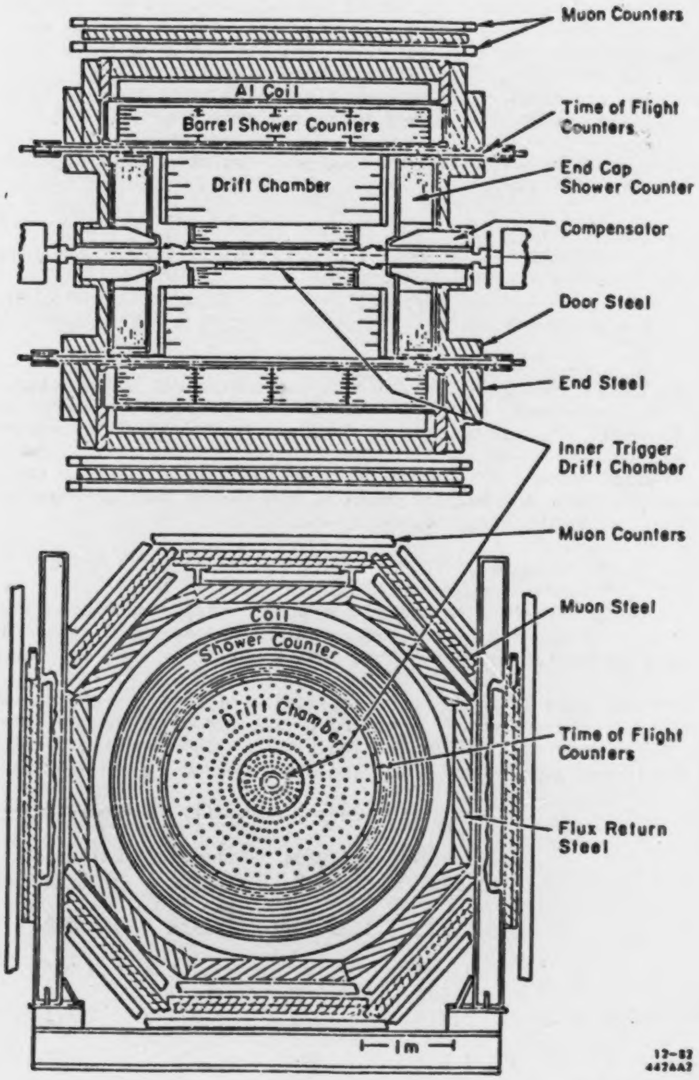
ATTACHMENT A

MARK III

LOCATION	SPEAR e^+e^- storage ring SLAC, Stanford, CA, USA
MAGNET	4.0 kG conventional aluminum coil
TRACKING	Drift chamber, O.D. 229 cm, length 234 cm 8 layers of cells, 2 stereo, 4 charge division 4 × 32 1-wire cells in trigger layer 12 × 32 sense-wire cells in inner dE/dx layer 16 × layer number, 3 sense-wire cells in outer layers 89% argon, 10% CO_2, 1% methane $(\Delta p/p)^2 = (1.5\%)^2 + (1.5\%\ p)^2$
SHOWER COUNTER	24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total) A cylindrical array of 1.3 cm × 2.9 cm × 3.5 m cells, 320 per layer readout at both ends with charge division; the inner 6 layers are read individually, and the outer 18 in groups of 3 80% argon, 20% methane $\sigma_\phi = 6$ mrad; $\sigma_\theta = 14$ mrad at 45°; $\sigma_E/E = 18\%/\sqrt{E}$
END CAPS	24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total) An array of rectangular 1.2 cm × 2.6 cm wide aluminum proportional tubes are glued between 1/2 X_0 layers of Pb 80% argon, 20% methane $\sigma_x = 0.8$ cm; $\sigma_y \sim 2$–4 cm
TIME-OF-FLIGHT	48 × 15 cm × 5 cm × 3.2 m Pilot F scintillation counters mounted in a cylindrical array around the drift chamber, read out by Amperex XP2020 photo-multipliers on each end of the scintillators $\sigma_t \simeq 150$–170 ps
MUON DETECTION	2 double layers of 5 cm diameter, 4.2 m long proportional tubes mounted outside a 20 cm Fe flux return and separated by an additional 13 cm of Fe absorber The array covers 2/3 of the solid angle $\sigma_\phi = 7$ mrad; $\sigma_\theta = 30$ mrad
TRIGGER	Uses timing information from 2 layers of the inner trigger chamber and a chronotron circuit to restrict the trigger to a ±45 ns interval Three layers of unfitted tracking information from the drift chambers are used to define tracks Triggering is on one track plus time-of-flight information or 2 tracks, solid angle ≃ 80%
LUMINOSITY MONITOR	4 scintillator + shower counter telescopes at 25 mrad

ATTACHMENT A

MARK III


Muon Counters
Al Coil
Barrel Shower Counters
Time of Flight Counters
Drift Chamber
End Cap Shower Counter
Compensator
Door Steel
End Steel
Inner Trigger Drift Chamber
Muon Counters
Coil
Shower Counter
Muon Steel
Drift Chamber
Time of Flight Counters
Flux Return Steel
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4. **What have been SPEAR's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: Highlights for experimental research at SPEAR since FY 1980 include the discovery of many new states of matter in the energy region higher than that at which the J/ψ was first found in 1974. Both the Crystal Ball and Mark III detectors have contributed to these discoveries which include the charmed states, eta-c eta-prime-c. Both groups have also found states which are strong candidates for "glueballs" - particles which contain no quarks among their constituents, but which are made solely of gluons. By studying the production and decay of these particles in detail, the Mark II group expects in FY 1984 and FY 1985 to establish their nature.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: The Mark III detector will be modified during FY 1984 to accommodate a different configuration of the SPEAR ring designed to increase the luminosity. The Crystal Ball detector was moved to (DESY) in 1982, where it is being used in the upsilon mass region ($\sim$9 - 11 GeV/c2) for detailed studies of the quark-antiquark system consisting of a bottom quark and its antiparticle.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to SPEAR. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: A rough estimate of the operating and equipment funds which can be attributed to the SPEAR program at SLAC are given in the table below. It must be recognized that neither SLAC nor DOE maintains accounting records in a fashion that allows the direct determination of the total resources expended on a particular subpart of the SLAC facility or experimental program.

The FY 1985 increase in SPEAR operating costs reflects the planned substantial decrease in the number of operating shifts allocated to the fixed-target program. This results in SPEAR bearing a larger share of the costs of operating the linear accelerator which are allocated on a per shift basis.

(Budget Authority in thousands)

	Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$10,926	$12,638	$12,442	$12,368	$17,252
In-House Research	1,600	2,172	2,102	2,175	2,752
Operations	8,107	9,545	9,067	9,020	13,146
Other Operating Expenses	1,219	921	1,273	1,173	1,354
Equipment	1,925	694	741	620	1,257

	Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
Construction	66	390	215	247	503
Accelerator Improvements	57	81	--	--	121
General Plant Projects	9	309	215	247	382
Total Funding	$12,987	$13,722	$13,398	$13,235	$19,012

7. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

Answer: SLAC receives no funding direct from any other Federal or state agency for its high energy physics research program. However, the Laboratory has operated the SPEAR colliding beam ring one-half time to provide beam for research conducted at the Stanford Synchrotron Radiation Laboratory, for which it receives reimbursement for associated incremental expenses. These funds are indicated in the response to question 3.0.3. In FY 1981 and FY 1982, these reimbursements for a total of $3,222,000 were paid by the NSF. Since FY 1982 these SSRL expenses have been funded through the DOE Basic Energy Sciences program.

8. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

Answer: A rough estimate of the manpower devoted to the SPEAR program is given in the table below. It must be recognized that neither SLAC nor DOE maintains records in a fashion that allows the direct determination of the total manpower devoted to a particular subpart of the SLAC facility or experimental program.

The FY 1985 increase in manpower allocated to SPEAR reflects the planned substantial decrease in the number of operating shifts allocated to the fixed-target program. This results in SPEAR being allocated a larger share of the manpower for operating the linear accelerator.

Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
245	241	203	218	264

9. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

Answer: Shift utilization is the important parameter for the SPEAR Program. During periods of SPEAR operation, the time is divided equally among SPEAR high energy physics research and SSRL. Consequently, full utilization for SPEAR would be 415 shifts of operation for high energy physics. On this basis the following table shows the percentage utilization of SPEAR.

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Operation for HEP as % of 415 shifts	85%	83%	93%	69%	70%

10. For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?

Answer: The research program at SPEAR has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment". This approved detector is used by the investigators to log a large class of events under a variety of operating conditions. The table below gives the numbers of such detector installations started, continued, and completed, in the period FY 1981 - FY 1985.

SPEAR Experiments Started, Running, and Completed by Year for FY 1981 - FY 1985, Inclusive

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Started	0	2	0	0	0
Running	1	3	1	1	1
Completed	0	2	0	0	0

11. What is SPEAR's user policy?

Answer: SPEAR is operated under the standard user policy of the Stanford Linear Accelerator Center which was described in response to question 3.0.8.

12. What is the mechanism by which specific research proposals for experiments at SPEAR are considered?

Answer: Experiments for SPEAR are considered in accordance with the standard procedures of the Stanford Linear Accelerator Center which were described in response to question 3.0.10.

13. How many research proposals have been submitted over the past five years, and how many of these have been approved?

Answer: The research program at SPEAR has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment". This approved detector is used by the investigators to log a large class of events under a variety of operating conditions. Proposals submitted for SPEAR detector installations and those approved by calendar year 1979 - 1983 follow:

	1979		1980		1981		1982		1983	
	SUB	APP	SUB	APP	SUB	APP	SUB	APP	SUB	APP
SPEAR	1	1	1	1	1	1	0	0	0	0

14. How many university personnel (i.e., faculty and students) have utilized SPEAR over the past five years?

Answer: Eighty-two university personnel have utilized SPEAR for high energy physics experiments over the past five years.

15. How many industrial researchers have utilized SPEAR over the past five years?

Answer: There have been no industrial researchers who have used SPEAR for high energy physics purposes over the past five years.

16. How many researchers from foreign institutions have utilized SPEAR over the past five years?

Answer: No researchers from foreign institutions have performed high energy physics research at SPEAR during the past five years.

17. What are the future development possibilities for SPEAR (including instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: Provision of a second detector at SPEAR, to occupy the presently unused East Pit, is a possibility. No specific plans to do so have yet been developed. A micro-beta insertion into the colliding beam detector region is planned for FY 1985, to increase the luminosity of SPEAR.

3.3 Positron-Electron Joint Project (PEP)

1. What new science is being explored by PEP? What scientific opportunities are being exploited?

Answer: The following examples illustrate the science being explored at PEP and the scientific opportunities that are being exploited.

1. Charmed Particle Lifetime

Five kinds of quarks are presently known. The fourth of these is called the "charmed" quark. The combination of a charmed quark with different kind of antiquark (or vice versa) produce a particle called a charmed meson. Measuring how long this meson exists before it decays into other particles provides an indirect measurement of the lifetime of its constituent charmed quark. The measured lifetime is less than a millionth of a millionth of a second, and the measurement of so short a lifetime required the use of an exceptionally clever technique. A special device called a vertex detector was used to allow a distinction to be made between the point at which the new particle was created and the point at which it decayed. This distance is only about 100 micrometers (a few times the thickness of a human hair), but a sampling of many different events of this kind made it possible to infer the average decay distance, and thus to calculate the lifetime of the particle.

2. Bottom Quark Lifetime

The lifetime of the fifth or bottom (b) quark has been measured in two different sets of experiments carried out at the PEP storage ring. The first measurement was made with the MAC detector, and this was soon followed by a similar measurement made with the Mark II detector. The measurements are in general agreement, with the value of the lifetime being set at slightly longer than a millionth of a millionth of a second. Although brief by ordinary standards, this lifetime is quite long in the natural time scale of the particles. In addition, because of interrelationships among the different kinds of quarks (they appear to come in pairs, with each pair forming a different "generation"), this work implies the existence of a sixth kind of quark, already named "top", but not yet discovered. The lifetime of the b quark is also an indirect indication of the mass of the predicted t quark, and is thus a guide as to how the t (top) quark can be searched for.

3. Tau Lepton Lifetime

The MAC and Mark II groups working at PEP have also been able to measure the lifetime of an elementary particle called the tau, which was discovered at SLAC in 1975, and which is an even heavier relative of the electron and its bigger brother, the muon. The sequence of electron, muon, tau has a mass relationship of roughly 1:200:4000, but in all other respects these three particles appear to behave in exactly similar ways. That there should be three such generations of electron-like particles is one of the most intriguing, and unexplained, aspects of research in this field. The two measurements recently performed at PEP agree on a tau lifetime of about three tenths of a millionth of a millionth of a second - a value that is consistent with the idea that the electron, muon and tau differ from each other only in their masses.

4. Electroweak Force Studies

Our present understanding of the electromagnetic and weak forces results in the prediction that the process by which electron-positron collisions in the PEP machine lead to the creation of a pair of muons should occur in an asymmetric manner. This is an important test of our ideas of electroweak unification, and the required experiments are now being carried out by several of the groups working at the PEP machine. Enough evidence is now available to provide general confirmation of the theory's prediction. The measurements made at PEP will be compared with the similar measurements made at somewhat higher energies at the German PETRA ring to determine how the observed asymmetry depends upon the energy of the initial collision.

5. Tests of Quantum Chromodynamics (QCD)

In a more general vein, all of the experiments now in progress at the PEP storage ring are collecting important information about how the initial process of electron-positron annihilation leads to the production of strongly interacting particles (hadrons), and of how the quark composition of these particles changes as they subsequently decay to lighter particles. These are the processes that the promising theory of the strong interactions, QCD, purports to describe, and they are thus tests of the theory. Definitive testing of QCD is still some distance away from us, both because the theory itself does not in general presently lend itself to precise prediction, and also because some of the proposed experimental tests will require a higher energies or a degree of precision that are presently unattainable.

6. Search for Unusual Particles

There is a very attractive but speculative theory called "supersymmetry" (SUSY) that can in principle incorporate the force of gravity within the framework of elementary particle theory. One of the predictions of this theory is that there should exist supersymmetric "partners" of the ordinary particles which differ from them only in a certain property (spin) and probably in mass. The MAC detector at PEP has already carried out search for two of the predicted kinds of supersymmetric particles ("selectron" and "photino"), and in fact at present has one potential candidate for a photino. It is much too early to get excited about this one event, but the subject itself is very important. In fact, a separate dedicated experiment to search for SUSY particles is now being set up in one of the research areas at PEP for operation next year.

2. **How does PEP's performance compare with any other storage rings in the world that are operating, under construction, or planned?**

Answer: PEP operates at a maximum center-of-mass energy of 36 GeV (18 GeV on 18 GeV). Its two nearest competitors in electron-positron colliding beam physics are the Cornell Electron Storage Ring (CESR) at 15 GeV center-of-mass energy located at Cornell University, Ithaca, New York and the 46 GeV storage ring PETRA at the German research center DESY in Hamburg, West Germany. PEP has the largest experimental program with five of the six available straight sections in use simultaneously. PETRA has four active interaction regions and Cornell two. The PEP program has concentrated on running at one energy, 29 GeV, and has the highest peak and average luminosity; it has in fact reached a higher level, 3.2×10^{31} m^{-2} sec^{-1}, than any other electron-positron storage ring.

There are a number of other electron-positron storage rings in operation or under construction. Those in operation include the SPEAR ring (3 to 6 GeV) at SLAC, DORIS (10 GeV) at DESY, and VEPP IV (14 GeV, design). There are three other facilities which are under construction: The Beijing Electron Positron Collider (BEPC) designed for up to 4.4 GeV center-of-mass capability, but designed for expansion to 10 GeV; Japanese project Tristan (60 GeV), which may eventually be part of an electron proton collider (25 GeV electrons on 300 GeV protons); and the Large Electron Positron Collider, LEP, at the European center CERN which will operate initially at 120 GeV center-of-mass energy and includes a planned Phase II improvement (after some initial physics) to as much as 240 GeV center-of-mass energy.

3. **What types of research instrumentation/experimental devices are available at PEP, and what are their capabilities?**

Answer: The five major experimental devices now in operation at PEP are the following: DELCO, HRS, MAC, Mark II and TPC. The properties of these five large detector systems are described in Attachments A through E.

In the sixth detector region, a number of specialized experimental setups have been used. At the present time, a neutral particle detector is being built for installation at this location. This detector consists of a lead glass/proportional chamber electromagnetic calorimeter along with charged particle veto elements. The purpose of this device is to provide detection and isolation of photons produced in e^+e^- collisions. Its initial use will be in an experiment to search for supersymmetric particles (photinos).

Attachment A

DELCO

LOCATION	PEP e^+e^- ring SLAC, Stanford, CA, USA
MAGNET	Open-geometry (aperture $\vert\cos\theta\vert < 0.78$) Pole-tip diameter 101 cm, separation 125 cm $B_0 = 3.3$ kG, $\int B dl = 1.8$ kG-m
TRACKING	Central (cylindrical) drift chambers: 94 cm maximum wire length, 12–49 cm radius Low mass (2.3% X_0) Depth (z) measurement by narrow angle stereo 16 points on tracks with $\vert\cos\theta\vert < 0.69$ Outer (planar) drift chambers: 285 cm wire length, 160 cm <radius> Depth measurement by wide angle stereo 6 points on tracks with $\vert\cos\theta\vert < 0.65$ Multiple hit digital electronics (4 ns bin width) $\sigma_p/p = \sqrt{(2\%\, p)^2 + (6\%)^2}$
CERENKOV COUNTER	1 atm. isobutane threshold counter ($\gamma_t = 19.1$) 36 cells each with (pTP-coated) 5″ RCA 8854 quantacon Radiator length 55–110 cm, $<\text{p.e.}> = 18$, $<N_0> = 80$ cm^{-1} $\sigma_t = 300$ ps Acceptance $\vert\cos\theta\vert < 0.62$
SHOWER COUNTERS	Barrel ($\vert\cos\theta\vert < 0.62$) : 48 Pb-scintillator counters, $6X_0$ Pole-tip ($0.79 < \vert\cos\theta\vert < 0.98$) : 36 Pb-scintillator BBQ counters, $5X_0$
TIME OF FLIGHT	52 counters 324 cm length, 180 cm <radius> $\sigma_t = 350$ ps Acceptance $\vert\cos\theta\vert < 0.67$
LUMINOSITY MONITOR	12 Pb-scintillator BBQ counters, $16X_0$ Acceptance 25–68 mrad relative to beam axis

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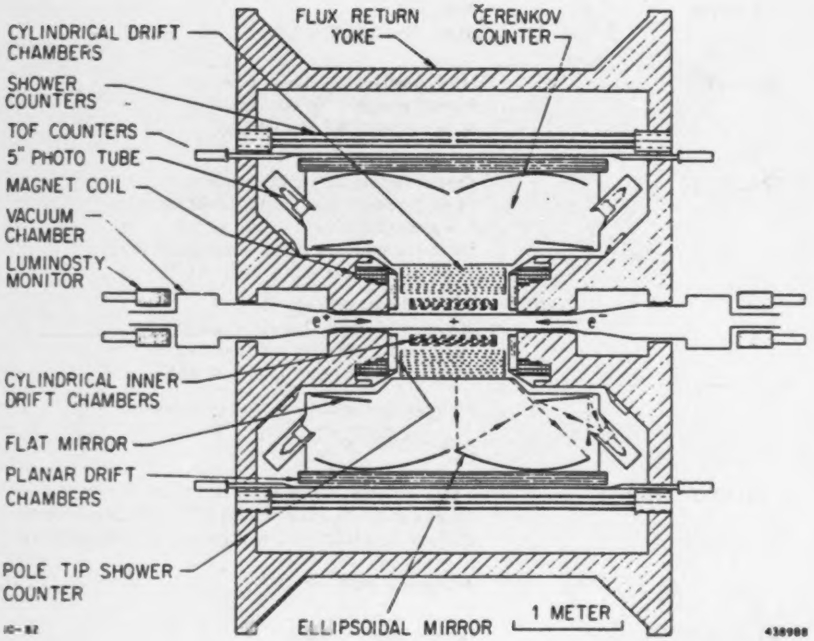
2. W.E. Slater et al., Nucl. Instr. & Meth. **154** (1978) 223.
3. D. Ouimette et al., IEEE Trans. NS 29, No. 1 (1982) 290.

DELCO


CYLINDRICAL DRIFT CHAMBERS
FLUX RETURN YOKE
ČERENKOV COUNTER
SHOWER COUNTERS
TOF COUNTERS
5" PHOTO TUBE
MAGNET COIL
VACUUM CHAMBER
LUMINOSTY MONITOR
e⁺
e⁻
CYLINDRICAL INNER DRIFT CHAMBERS
FLAT MIRROR
PLANAR DRIFT CHAMBERS
POLE TIP SHOWER COUNTER
ELLIPSOIDAL MIRROR
1 METER
10-82
438988

XBL 831-7897

Attachment B

High Resolution Spectrometer (HRS)

LOCATION	PEP e^+e^- ring SLAC, Stanford, CA, USA
MAGNET	16 kG (superconducting) Diameter = 4 m, length = 3.8 m
TRACKING	Inner cylindrical drift chamber (15 layers): 2.53 m long at 0.21–1.02 m radius Outer drift tubes (2 layers): 3.66 m long at 1.90 m radius Resolution $\sigma_p/p < 0.1\%$ p for p = 14.5 GeV/c
SHOWER COUNTERS	40 Modules $11X_0$ Pb-scint. sandwich inside the coil; 1 layer PWC $\sigma_E/E = 16\% / \sqrt{E}$ 2 samples in depth
END CAPS	40 Modules $8X_0$ Pb-scint. sandwich Wave shifter readout; 1 layer PWC $\sigma_E/E = 20\% / \sqrt{E}$
TIME OF FLIGHT	From front $3X_0$ of shower counter at r = 1.95 m σ_τ = 170 ps for Bhabhas σ_τ = 350 ps for hadrons
PHOTO-IONIZATION CERENKOVS	704 segments in 11 toroids 15 atmospheres give (K, p)π separation between 1 and 4 GeV/c
LUMINOSITY MONITOR	Telescope with Pb-glass at 32–60 mradians

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3. J. Chapman et al., IEEE Trans. on Nuc. Sci. **NS 29** (1982) 332.
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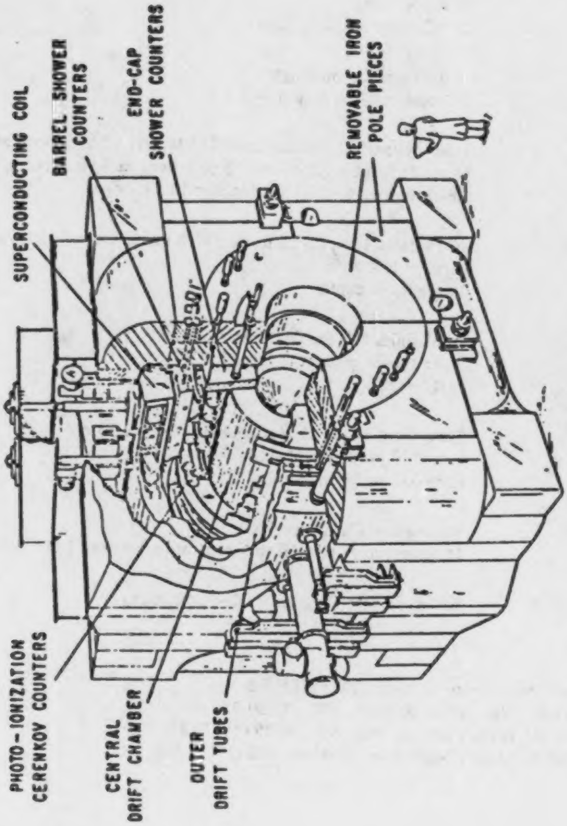
High Resolution Spectrometer


SUPERCONDUCTING COIL
BARREL SHOWER COUNTERS
END-CAP SHOWER COUNTERS
REMOVABLE IRON POLE PIECES
PHOTO-IONIZATION CERENKOV COUNTERS
CENTRAL DRIFT CHAMBER
OUTER DRIFT TUBES

HIGH RESOLUTION SPECTROMETER

ARGONNE-INDIANA-LBL-MICHIGAN-PURDUE-SLAC

XBL 831-7884

Attachment C

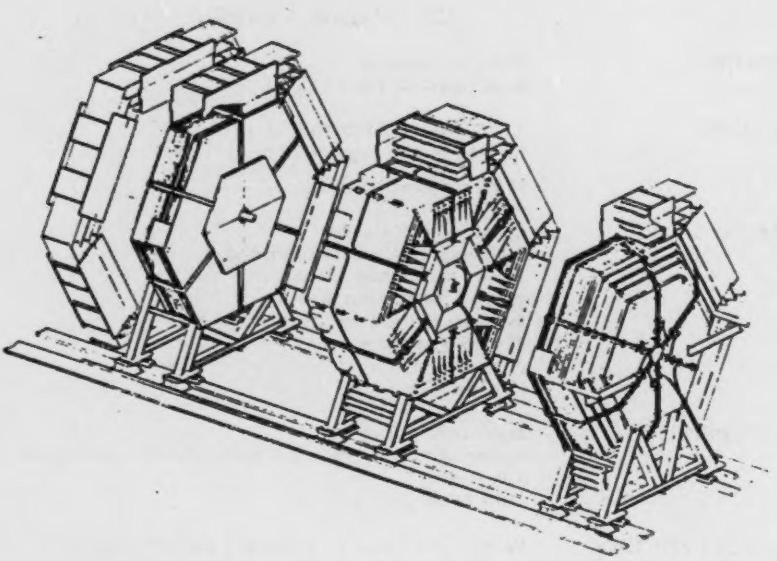
MAC (MAgnetic Calorimeter)

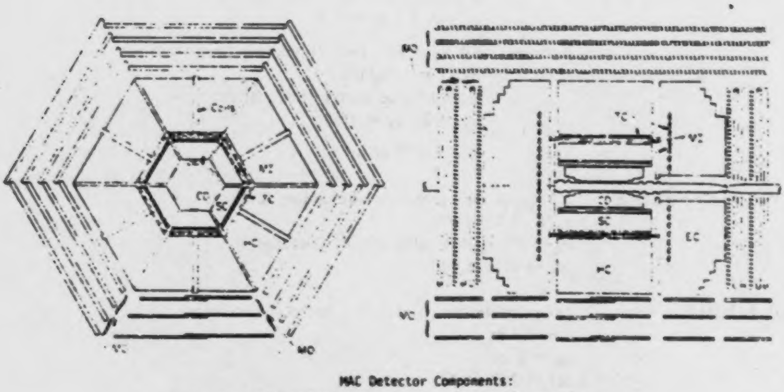
LOCATION	PEP e^+e^- storage ring SLAC, Stanford, CA, USA
MAGNETS	5.7 kG solenoid, 7.5 cm thick Al coil Diameter = 1 m, length = 2.3 m 17 kG iron toroids, 1 m thick
TRACKING	Cylindrical drift chamber 2.2 m long, 12–45 cm tracking radius Argon - 10% methane at 1 atm. 10 layers, double sense wires ≥ 5 points on tracks over $\Delta\Omega = 95\%$ of 4π 3° stereo gives $\Delta z = 4$ mm dE/dx to ±15% $\sigma_p/p = 6.5\%\ p$
MUON DETECTION	Muon tracking chambers 4 planes of 10 cm diameter drift tubes surrounding magnetized iron toroids $\sigma_p/p = 30\%$ $\Delta\Omega = 97\%$ of 4π
SHOWER DETECTORS	Barrel: 14 X_0 of Pb - proportional chamber sandwich $\sigma_E/E = 20\%/\sqrt{E}$ z-coordinate from charge division $\sigma_\phi = 0.8°$, $\sigma_\theta = 1.3°$ Endcaps: 14 X_0 of Fe - proportional chamber sandwich $\sigma_E/E = 45\%/\sqrt{E}$ ϕ-coordinate from cathode strips $\sigma_\phi = 2°$, $\sigma_\theta = 1.5°$ Total: $\Delta\Omega = 97\%$ of 4π
HADRON CALORIMETER	5.5 λ_{abs} of Fe - proportional chamber sandwich $\sigma_E/E = 75\%/\sqrt{E}$ $\sigma_\theta = 2°$; $\sigma_\phi = 1°$ (barrel), 4° (endcaps) $\Delta\Omega = 97\%$ of 4π
TIME OF FLIGHT	144 scintillation counters (72 barrel, 72 endcaps) r = 1.3 m $\Delta t = 1$ ns $\Delta\Omega = 97\%$ of 4π
LUMINOSITY MONITOR	4 scintillator/shower counter telescopes at 32 mrad horizontally

REFERENCES

1. R.L. Anderson et al., IEEE Trans. NS 25, (1978) 340.
2. W.T. Ford, SLAC-PUB-2894, March 1982 (Proceedings SLAC International Conference on Instrumentation for Colliding Beams).

MAC (MAgnetic Calorimeter)




Coils
MI
TC
CD
SC
HC
MO
MI
TC
MI
CD
SC
HC
EC
MO

MAC Detector Components:

CD - Central Drift Chamber
SC - Shower Chamber (Central)
TC - Trigger/TOF Scintillators
HC - Hadron Calorimeter (Central)
EC - End-cap Shower and Hadron Calorimeters
MO, MI - Muon Drift Chambers
Coils - Solenoid and Toroid

XBL 831-7898

Attachment D

MARK II

LOCATION	PEP e^+e^- storage ring SLAC, Stanford, CA, USA
MAGNET	4.6 kG Al coil solenoid, 1.5 m radius (currently running at 2.3 kG)
TRACKING	Central drift chamber: Active length = 2.64 m, inner radius = 0.41 m, outer radius = 1.45 m 6 axial layers, 10 stereo layers ($\pm 3°$) 50% ethane, 50% argon $\sigma \simeq 200\ \mu$ Vertex drift chamber: Cylindrical drift chamber, 1.2 m long, inner radius = 10 cm, outer radius = 35 cm Only axial wire layers (4 near r = 12 cm, 3 near r = 30 cm) $\sigma \simeq 100\ \mu$ Be beam pipe ($0.006X_0$) Combined $(\Delta p/p)^2 = (0.015)^2 + (0.01p)^2$ Tracks extrapolated to interaction point within 100 μ
SHOWER COUNTERS	8 modules of Pb-liquid argon ($15X_0$ each), arranged in octagon outside coil Covers 64% of 4π 2 mm Pb sheets separated by 3 mm liquid argon gaps 37 layers ($0.4X_0$ sampling) are ganged to provide 6 samples in depth Readout in 3.8 cm wide strips in ϕ, θ, u directions $\Delta E/E \simeq 13\%/\sqrt{E}$
TIME OF FLIGHT	48 scintillation counters read out at both ends Cover 75% of 4π 1.50 m flight path at $\theta = 90°$; $\sigma = 340$ ps K,π separation up to 1.35 GeV/c at 1σ level
END CAPS	2 layers Pb-proportional chamber ($5X_0$) with 4 successive cathode strip readouts (θ, ϕ, R-spiral, L-spiral) 50% argon, 50% ethane
MUON DETECTION	Proportional tubes interleaved with steel absorber (4 layers each for total thickness of 1 m) covering 55% of 4π
SMALL ANGLE TAGGING LUMINOSITY MONITOR	6 planar drift chambers followed by shower counters Octagonal shower counters cover 22 mrad $< \theta <$ 80 mrad contain 18 layers 1/4″ Pb and 1/2″ scintillator, read out with BBQ wave shifter, front 5 layers separately from back 13 $\Delta E/E = 15.5\%/\sqrt{E}$ 3 sets of scintillation counters

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2. W. Davies White et al., Nucl. Instr. & Meth. 160 (1979) 227.
3. G.S. Abrams et al., IEEE Trans. Nucl. Sci. NS 25 (1978) 1, *ibid* 309, and NS 27 (1980) 59.
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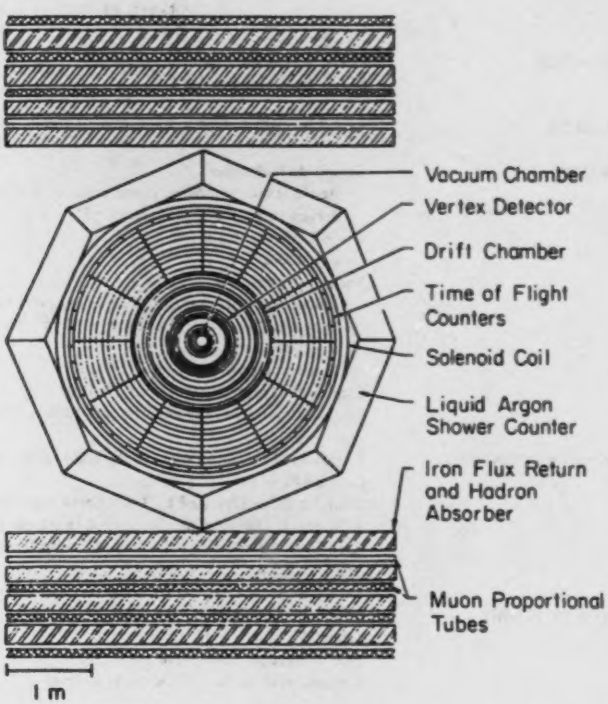
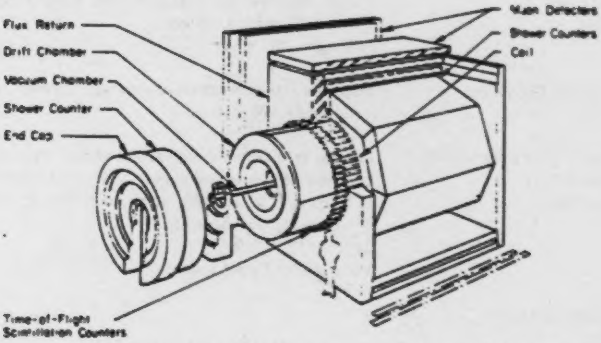
MARK II


Vacuum Chamber
Vertex Detector
Drift Chamber
Time of Flight Counters
Solenoid Coil
Liquid Argon Shower Counter
Iron Flux Return and Hadron Absorber
Muon Proportional Tubes
1 m


Flux Return
Drift Chamber
Vacuum Chamber
Shower Counter
End Cap
Muon Detectors
Shower Counters
Coil
Time-of-Flight Scintillation Counters

Attachment E

TPC

LOCATION	PEP e^+e^- ring, Interaction Region (IR) 2 SLAC, Stanford, CA, USA
MAGNET	1982–83: 4 kG Al coil solenoid ($1.32X_0$ coil package) 1984: 14.5 kG superconducting coil ($0.86X_0$ package) Diameter = 2.15 m, length = 3.0 m
TRACKING	Time Projection Chamber (TPC) 2.0 m long (in z) at 20 to 100 cm radius (r) Argon-methane (80%–20%) at 8.5 atm. Max. drift 1.0 m in 20 μsec, 75 kV/m drift electric field 183 proportional wire hits on tracks with $\lvert\cos\theta\rvert < 0.71$, each wire gives r,z and amplitude for six 60° sectors at each end and provides dE/dx meas. by multiple ionization sampling 15 3-dim. space points from induced cathode signals on several of 13,824 channels to give r, ϕ, and z (from the drift time), for $\lvert\cos\theta\rvert < 0.71$ ≥2 3-d points and ≥15 wire hits over 97% of 4π sterad Track pair resolution of 1–2 cm dE/dx ±3.5% for Bhabhas ±4.0% for tracks in jet events with ≥120 samples $\sigma_p/p^2 = \pm 3.6\%$ for $p \geq 2$ GeV/c position resolution in bending plane is 190 microns and in axial (z) direction 340 microns; presently low magnet field and drift distortions increase σ_p/p^2 Inner drift chamber at 13 to 19 cm radius 8.5 atm Ar-CH_4 (80%–20%), 150 microns in bend plane 1.2 m long covering 95% of 4π, with 4 axial layers Outer drift chamber at 1.19 to 1.24 m radius 1 atm Ar-CH_4 (80%–20%), 200 microns in bend plane 3 m long covering 77% of 4π, with 3 axial layers
POLE-TIP CALORIMETER	Gas, proportional mode, sampling Pb-laminate calorimeter 2 modules, $13.5X_0$ deep, at $z = 1.1$ m, covering 18% of 4π Argon-methane (80%–20%) at 8.5 atm; total of 51 samples Three 60° stereo views, each with 13 and 4 samples in depth Projective strip geometry with 8 mrad angular segment $\sigma_E/E = \pm 11\%/\sqrt{E}$, below 10 GeV ±6.0% for Bhabhas at 14.5 GeV
HEXAGONAL CALORIMETER	Gas, limited Geiger mode, sampling Pb-laminate calorimeter 6 modules, $10X_0$ deep, 4.2 m long at 1.2 m radius Argon-ethyl bromide (96%–4%) at 1 atm Solid angle coverage of 75% (90% including PTC) 3 correlated 60° stereo views using wire and cathode signals in 40 samples (27 and 13 samples in depth) Projective strip geometry with 9 mrad angular segment $\sigma_E/E = \pm 14\%/\sqrt{E}$, below 1 GeV ±12% for Bhabhas at 14.5 GeV
MUON DETECTOR	Magnet flux return + 2 layers iron, total 810 g/cm Triangular, double layer, extruded Al proportional tubes Argon-methane (80%–20%) at 1 atm. 3 layers with axial wires and 4th layer at 90 deg. Endcap with 3 layers provides 98% of 4π sterad coverage Resolution = 1 cm, expect 3 mm when operated as drift tube
TRIGGER	≥2 charged over 85% of 4π sterad; neutral energy of ≥4 GeV, or energy in two or more calorimeter modules of ≥1.5 GeV; ≥1 charged and neutral energy of ≥750 MeV or energy in two or more calorimeter modules of ≥1.5 GeV

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2. IDC: W. Gorn et al., IEEE Trans. NS 26 (1979) 67.
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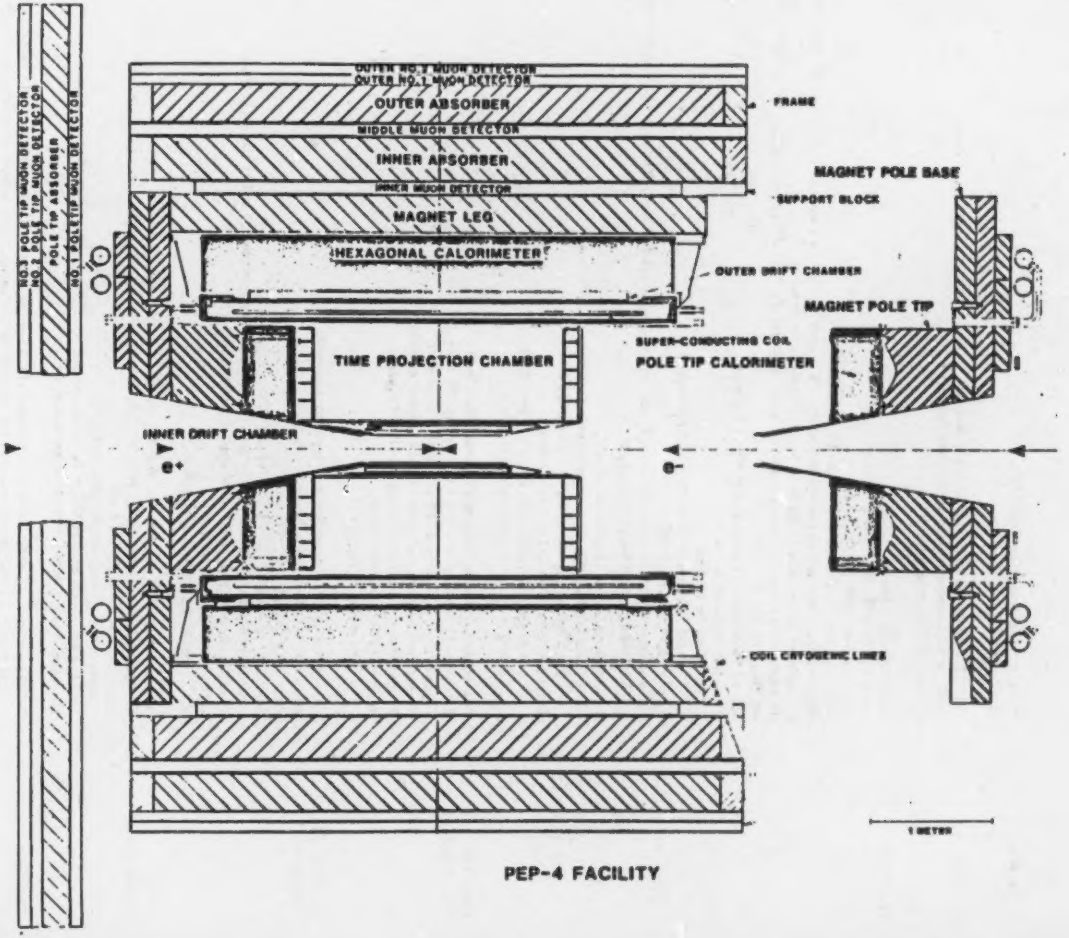
OUTER NO.2 MUON DETECTOR
OUTER NO.1 MUON DETECTOR
OUTER ABSORBER
MIDDLE MUON DETECTOR
INNER ABSORBER
INNER MUON DETECTOR
MAGNET LEG
HEXAGONAL CALORIMETER
TIME PROJECTION CHAMBER
INNER DRIFT CHAMBER
FRAME
MAGNET POLE BASE
SUPPORT BLOCK
OUTER DRIFT CHAMBER
MAGNET POLE TIP
SUPER-CONDUCTING COIL
POLE TIP CALORIMETER
COIL CRYOGENIC LINES
NO.3 POLE TIP MUON DETECTOR
NO.2 POLE TIP MUON DETECTOR
POLE TIP ABSORBER
NO.1 POLETIP MUON DETECTOR
e+
e-
1 METER

PEP-4 FACILITY

4. **What have been PEP's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: Although PEP started running regularly for experimental research earlier, during the period FY 1981 to the present it has steadily improved in producing higher luminosity and most major new results have been achieved in the latter part of the period. Its chief rival in studying electron-positron collisions, PETRA, has been surpassed in integrated luminosity. PEP, with its major detector facilities (MAC, HRS, DELCO, TPC, and Two Gamma) has produced important new results which include the first definitive measurements of the lifetimes of the tau meson, the charmed D-meson and the b-quark. Using its relatively high luminosity the detector groups have achieved high accuracy in measuring important details of the recently unified electroweak interaction as well as some of the quantitative predictions of quantum chromodynamics. It is expected that the work in FY 1984 and FY 1985 will provide more stringent tests of these important theories as well as more precise measurements of the decays of recently discovered states of matter, both lifetimes and relative modes of decay.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: In FY 1984 a new single-purpose experiment is being installed in Interaction Region 10 at PEP; this will be a search for supersymmetric particles. Also, the Mark II detector is now undergoing a major upgrading program in preparation for further operation for research at PEP and then a transfer to the Stanford Linear Collider. In addition, several of the other PEP detectors have had, or are planning, relatively minor changes or additions to their systems.

The luminosity of the PEP storage ring has been steadily increasing during this period; the improvements include mini-beta insertions at the beam collision locations, and a number of minor operational improvements developed to a large extent by the PEP beam operations crews. A further increase in luminosity is planned, with the provision of "micro-beta" insertions at the beam collision locations.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to PEP. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: A rough estimate of the operating and equipment funds which can be attributed to the PEP program at SLAC are given in the table below. It must be recognized that neither SLAC nor DOE maintains accounting records in a fashion that allows the direct determination of the total resources expended on a particular subpart of the SLAC facility or experimental program.

The FY 1985 increase in PEP operating costs reflects the planned substantial decrease in the number of operating shifts allocated to the fixed-target program. This results in PEP bearing a larger share of the costs of operating the linear accelerator which are allocated on a per shift basis.

(Budget Authority in thousands)

	Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$27,106	$28,375	$32,826	$37,332	$46,656
In-House Research	3,810	4,730	3,947	6,025	6,772
Operations	20,422	20,993	24,235	28,458	34,748
Other Operating Expenses	2,874	2,652	4,644	2,849	5,136
Equipment	3,497	2,930	3,538	2,255	1,426
Construction	164	848	2,761	759	1,306
Accelerator Improvements	142	175	--	--	314
General Plant Projects	22	673	585	759	992
PEP Claims	--	--	2,176	--	--
Total Funding	$30,767	$32,153	$39,115	$40,346	$49,388

7. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

   Answer: SLAC receives no funding direct from any other Federal or state agency for high energy physics purposes at the PEP facility. However, some of the university-based physicists who perform research at the PEP facility receive their direct financial support from NSF grants.

8. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

   Answer: A rough estimate of the manpower devoted to the PEP program is given in the table below. It must be recognized that neither SLAC nor DOE maintains accounting records in a fashion that allows the direct determination of the total manpower devoted to a particular subpart of the SLAC facility or experimental program.

   The FY 1985 increase in manpower allocated to PEP reflects the planned substantial decrease in the number of operating shifts allocated to the fixed-target program. This results on PEP being allocated a larger share of the manpower for operating the linear accelerator.

Estimate FY 1981	Estimate FY 1982	Estimate FY 1983	Estimate FY 1984	Estimate FY 1985
627	569	559	660	708

9. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

   Answer: Shift utilization is the important parameter for PEP. Full shift utilization would be 830 shifts per year. On this basis, the following table shows the percentage of PEP utilization.

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Operation as % of 830 shifts	85%	83%	93%	69%	70%

10. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer: The research program at PEP has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment". Such an approved detector facility is used by the investigators to log a large class of events under a variety of operating conditions. The table below gives the numbers of such detector installations started, continued, and completed, in the period FY 1981 - FY 1985.

PEP Experiments Started, Running, and Completed by Year for FY 1981 - FY 1985, Inclusive

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Started	1	1	0	0	1
Running	6	7	7	4*	7
Completed	0	0	1	0	0

* PEP-4 and PEP-9 off to install superconducting magnet.

11. **What is PEP's user policy?**

Answer: PEP operates under the standard user policy for the Stanford Linear Accelerator Center, which was described in response to question 3.0.8.

12. **What is the mechanism by which specific research proposals for experiments at PEP are considered?**

Answer: PEP experiments are considered under the standard procedures of the SLAC which were described in response to question 3.0.10.

13. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

Answer: The research program at PEP has been concentrated largely on experiments using large, complex detector installations. Each detector installation is initially approved as an "experiment". Such an approved detector facility is used by the investigators to log a large class of events under a variety of operating conditions.

The five major detector facilities at PEP - Mark II, MAC, HRS, DELCO and TPC, were proposed and approved prior to this period. Their continued operation has produced the major part of important new results in physics at PEP. During the period 1979 - 1984 two new proposals for such installations have been submitted and both were approved (one in 1979 and one in 1983).

14. **How many university personnel (i.e., faculty and students) have utilized PEP over the past five years?**

Answer: Two hundred ninety-one university personnel have been involved in experiments at PEP over the past five years.

15. **How many industrial researchers have utilized PEP over the past five years?**

Answer: There have been no industrial researchers utilizing PEP over the past five years.

16. **How many researchers from foreign institutions have utilized PEP over the past five years?**

Answer: Twenty-nine researchers from foreign institutions have been involved in experiments at PEP over the past five years.

17. **What are the future development possibilities for PEP (including instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

Answer: Two new future detectors, replacements for the High Resolution Spectrometer (HRS) and for the Mark II detector, have been contemplated. Detailed plans for these detectors have not yet been developed.

In 1983, SLAC commissioned a study group to make recommendations on possible future improvements to the PEP machine. Two principal ideas were considered -- a possible increase in energy, and a possible increase in luminosity. The former idea was rejected while the proposal for a significant luminosity increase was supported and is included in the FY 1985 Presidents Budget Request. To implement the latter proposal, plans have been developed for "micro-beta" insertions at the beam collision locations, to provide for a significant luminosity increase.

3.4 SLAC Linear Collider (SLC)

1. **What new science will be explored by the SLC? What scientific opportunities will be exploited?**

   Answer: The SLC project has two primary scientific/technical goals. The first of these is to test the feasibility of the linear collider concept. This technique is new and no colliding beam facility has even been built using it. Linear colliders have the promise of providing electron-positron colliding beams at very high energies much more economically than electron-positron storage rings, which is the current operational method used throughout the world. There are a number of key technical problems which must be solved before the linear collider concept can be considered for a very high energy facility, and the SLC is intended to demonstrate that solutions to some of these are in hand.

   The second purpose of the SLC, which follows successful achievement of the accelerator R&D goal, is to explore electron-positron colliding beam physics in a new energy region.

   The SLC will operate at center-of-mass energies up to 100 GeV; this energy could eventually be increased to about 140 GeV should the prospective physics so warrant. The primary initial emphasis of the SLC program will be the study of the physics made accessible by copious production of the Z^o. This physics bears critically upon important questions related to the force unification schemes. The main areas of physics interest that the SLC could address are as follows:

   - precision study of the properties of the Z^o and its decay modes
   - electroweak interactions at energies beyond the Z^o
   - study of the quantum electrodynamics properties of quarks and gluons
   - search for new phenomena, e.g., Higgs bosons
   - search for the top quark
   - study of polarization effects (this is a unique capability of the SLC)

2. **How will the SLC's performance compare with any other electron-positron colliders in the world that are operating, under construction, or planned?**

   Answer: The SLC is designed to produce e^+e^- collisions at center-of-mass energies up to 100 GeV, with a luminosity of about 6×10^{30} cm^{-2} sec^{-1}. The SLC will have a single beam interaction point, and it is expected to begin operation for physics early in 1987. The only other machine that will be comparable to the SLC is the LEP e^+e^- storage ring now being constructed at the CERN laboratory. In its first phase the Large Electron Positron collider will produce center-of-mass energies up to ~120 GeV with a luminosity comparable to that of the SLC. LEP will have four active interaction regions, and it is expected to begin operating in 1989. Both SLC and LEP are expandable in energy, should that become warranted: SLC to 140 GeV, and LEP to about 240 GeV. There are, however, no specific plans to expand the SLC energy beyond the 100 GeV CMS energy which is quite adequate to study the exciting Z^0 physics; whereas the CERN LEP is planned to go to higher energies in a second phase. SLC has several unique advantages over LEP at this energy, including the possibility of polarized beams and of placing detection systems very close to the interaction point to study directly short-lived particle states.

3. **What types of research instrumentation/experimental devices will be available at this facility, and what will be their capabilities?**

Answer: The first detector planned for use at SLC will be the upgraded Mark II detector. This device will have the advantage of being a tried and proven detector, having been operated first at the Positron-Electron Project (PEP) ring before transfer to SLC. The second SLC detector, planned to be ready by 1989, will be a new detector specifically designed for physics at the SLC called the Stanford Linear Detector (SLD). Both the Mark II and the SLD are staffed by physicists from many different institutions in the U.S. and also some foreign participants. The upgraded Mark II detector is expected to have good vertex detection and location capability, precise central tracking in its magnetic field, and excellent electromagnetic shower measuring capability. The upgrades are to be completed in time for the final configuration to have been completely tested at PEP before it is set up at the SLC. In addition to improvements in vertex detection, central tracking, and shower measurement, and optimization for the higher energy of SLC, the SLD is expected to have excellent measuring capabilities for hadronic showers.

4. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: The funding related to the SLC is given in the following table.

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Operating	$ 3,697	$ 8,747	$17,003	$ 9,700	$ 9,500
Other Operating Expenses	$ 3,697	$ 8,747	$17,003	$ 9,700	$ 9,500
Equipment	637	2,263	1,118	3,800	8,000
Construction	1,707	908	315	32,000	60,500

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
SLC	--	--	--	32,000	60,500
PE&D	750	908	315	--	--
General Plant Projects	957	--	--	--	--
Total Funding	$ 6,041	$11,918	$18,436	$45,500	$78,000

5. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

   Answer: SLAC receives no funding from any other Federal or state agency for SLC R&D or construction. It is likely that some of the university-based participants in the Stanford Linear Detector (SLD) effort will receive their research funding from the National Science Foundation.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

   Answer: A rough estimate of the manpower devoted to the SLC program is given in the table below. It must be recognized that neither SLAC nor DOE maintains records in a fashion that allows the direct determination of the total manpower devoted to a particular subpart of the SLAC facility or experimental program.

FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
98	210	310	177	282

7. **What will be this facility's user policy?**

   Answer: The SLC will function under the standard user policy for the Stanford Linear Accelerator Center which was described in response to question 3.0.8.

8. **What is the mechanism by which specific research proposals for experiments at the facility are being considered?**

   Answer: The mechanism for considering SLC proposals will be the standard SLAC procedure as described in response to question 3.0.10.

9. **How many research proposals have been submitted, and how many of these have been approved?**

   Answer: Nine proposals for construction of SLC detector facilities were received in 1982 and reviewed by SLAC. The Mark II upgrade proposal was resubmitted in final form, and it was approved as the first SLC detector in 1983. The earliest version of the Stanford Linear Detector (SLD), a completely new detector, was first proposed in a letter of intent as the first SLC detector. This was turned down along with the other candidates at the time of the Mark II approval. Subsequently, the Director, with the advice of the SLAC Experimental Program Advisory Committee, has approved an improved version of the SLD as the second SLC detector. Proposals for experimental use of these facilities will be considered in about two years.

10. **What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

Answer: At present, there are no specific plans for future development of SLC. It is not likely that any plans would be developed until after construction has been completed and the SLC is brought into operation. The future program of SLC will clearly be influenced by developments at the European LEP facility which are not known at this time.

D. NON-ACCELERATOR HIGH ENERGY PHYSICS EXPERIMENTS

1. For the period FY 1981 - FY 1985, please provide actual and estimated funding levels (including operating expenses and capital equipment) of all non-accelerator high energy physics experiments, by DOE laboratory and by university involved. Also, please indicate the level of other agency funding (e.g., NSF).

Answer: The following table provides the requested information:

Non-Accelerator High Energy Physics Experiments
(Total Expenditures in Thousands)

		Operating Funds		Cap. Equipment			
		FY 1981 - 1984	FY 1985 (Est.)	FY 1981 - 1984	FY 1985 (Est.)	DOE Total	Other Funding
Proton Decay Experiments							
IMB	UC Irvine	$2,140	$ 650	$2,100	$250	$5,140	$
	U. of Michigan	2,140	650	2,100	250	5,140	
	BNL	0	0	0	0	0	
		4,280	1,300	4,200	500	10,280	
HPW	Harvard U.	2,000	400	600	0	3,000	
	Purdue U.	1,410	200	285	0	1,895	
	U. of Wisc.	1,590	340	40	0	1,970	
		5,000	940	925	0	6,865	
Soudan I & II	ANL	400	800	295	800	2,295	State of Minn.
	U. of Minnesota	1,050	860	195	0	2,105	700
	Tufts U.	40	90	0	0	130	U.K.
		1,490	1,750	490	800	4,530	500
	Subtotal	10,770	3,990	5,615	1,300	21,675	
Magnetic Monopole Searches							
U. of Pennsylvania		1,235	410	45	0	1,690	NSF
Stanford University		500	250	0	0	750	315
Texas A&M University		280	75	0	0	355	
Cal. Tech.		200	75	0	0	275	
ANL		10	10	0	0	20	
	Subtotal	2,225	820	45	0	3,090	
Quark Searches							
ANL		360	120	45	15	540	
San Francisco State U.		195	75	0	0	270	
Univ. of Minnesota		75	30	0	0	105	
Univ. of Pittsburgh		65	20	10	0	95	
NBS		20	10	0	0	30	NBS
	Subtotal	715	255	55	15	1,040	100

		Operating Funds		Cap. Equipment			
		FY 1981 – 1984	FY 1985 (Est.)	FY 1981 – 1984	FY 1985 (Est.)	DOE Total	Other Funding
Double Beta Decay Searches							
	Battelle	$ 630	$130	$ 0	$ 0	$ 760	$
	UC Irvine	480	140	0	0	620	
	Mt. Holyoke	65	35	0	0	100	
	UC Santa Barbara	800	150	0	0	950	
	Subtotal	1,975	455	0	0	2,430	
ν Oscillations							
	UC Irvine	860	240	0	0	1,100	
ν_e Interactions							
	UC Irvine	200	65	0	0	265	
Tritium End-Point							
	Rockefeller U.	200	50	150	0	400	
Precision α							
	NBS	60	15	0	0	75	NBS 700
Cosmic Rays							
DUMAND	U. of Hawaii	370	30	0	0	400	
	Cal. Tech.	20	10	30	0	60	
	UC Irvine	250	50	0	0	300	
	Purdue U.	20	60	0	0	80	
	U. of Wisc.	80	50	0	0	130	
	Subtotal	740	200	30	0	970	
High Energy Gamma Rays	Smithsonian	185	85	0	0	270	
	Iowa State U.	185	75	0	0	260	
	U. of Hawaii	100	0	0	0	100	
	Subtotal	470	160	0	0	630	
High Energy Gamma	U. of Wisc.	270	150	65	0	485	
	Purdue U.	40	140	0	0	180	
	U. of Hawaii	0	30	0	0	30	
	Subtotal	310	320	65	0	695	
Emulsion	U. of Wash.	820	215	0	0	1,035	
Cosmic Ray Subtotal		2,340	895	95	0	3,330	
TOTAL		$19,345	$6,785	$5,960	$1,315	$33,405	

2. Please provide a description of current non-accelerator high energy physics experiments, including a description of the science being explored by each, as well as the experimental equipment being used. What new experiments are being planned for the remainder of FY 1984 and in FY 1985?

Answer: Some 25 non-accelerator high energy physics experiments are currently being funded by the DOE. The main effort (see table attached to Question D.1.) is being expended on three principal types of experiments --the searches for proton decay, magnetic monopoles, and double beta decay-- all of which are investigating predictions of new theories which are attempting to unify either three of the four or all four of the basic forces of nature. This set is usually called the grand unification theories (or GUT theories for short).

Until recently most physicists believed that protons were absolutely stable, that magnetic monopoles never existed and could not exist, and that the decay of a nucleus by the simultaneous emission of two beta rays (either positively or negatively charged electrons) together with no emission of any neutrinos was absolutely forbidden. However, the new grand unification theories predict these phenomena. Thus, it is imperative to search for their existence in order to prove, disprove, or modify these theories.

Proton Decay Searches

Three large experiments are in progress in this country (together with four or five in the rest of the world) searching for proton decay using various methods for attacking the problem. Since the predicted proton lifetime is very long (>10^{29} years), a very large mass must be monitored continuously over a long period of time (minimum of 10^{30} protons or more for a year or more). Also, the experiment must be performed in a deep mine in order to reduce drastically the number of cosmic ray particles passing through the apparatus.

The largest proton decay apparatus in the world is that of the IMB (Irvine, Michigan, Brookhaven) experiment. It is basically a huge tub of pure water (8,000 tons). A proton decay in the water would emit fast particles which turn would emit light that would be observed by over 2,000 photomultiplier tubes lining the periphery of the tub.

The HPW experiment (Harvard, Purdue, Wisconsin) is a similar, but smaller, tub of water in which the photomultiplier tubes are distributed uniformly throughout the water volume.

The Soudan apparatus is quite different in that the predominant mass is in thin iron plates. Proton decay particles would emerge from the thin plates and then be detected in drift chambers. This experiment is quite different from the two water experiments in that it would detect slower particles from more complex modes of decay.

All of the above experiments are also involved in other important studies besides searching for proton decay. In particular, they are also searching for magnetic monopoles and are investigating other cosmic ray phenomena, both of which are described more fully below.

Magnetic Monopoles Searches

In addition to the three large experiments discussed above which have monopole detection capabilities, several smaller studies (see table attached to question D.1.) are being conducted searching for magnetic monopoles. One possible candidate has been found and published by Cabrera of Stanford University, but more must be detected before their existence is established.

Cabrera's technique involves detecting an electric current pulse in a wire coil induced by the magnetic field of the monopole passing through the coil, somewhat analogous to the current pulse induced when a bar magnet passes through a coil. Most of the other experiments detect the ionization in various materials caused by the passage of the monopole through the materials, ionization which is similar to that caused by "ordinary" electrically charged particles, such as electrons, protons, and mesons, passing through the materials. The monopoles would be distinguished from the "ordinary" particles by inducing a much different amount of ionization, while traveling at a much slower velocity than other particles. This slow velocity should be very easily timed between two counters.

To date, no monopoles have been seen by this second technique, but the major experiments of this type have only recently begun to operate.

Double Beta Decay Searches

For many years experimenters from both high and low energy physics have been searching for neutrinoless double beta decay, in which an unstable nucleus is transformed into another of the same atomic mass number but differing by two units of electric charge. Two electrons have to be observed of exactly equal energy and exactly opposite momentum. The GUT theories make new predictions about this phenomenon, and thus the search has been intensified. Most of the new experiments are also being done in deep caves or mines in order to reduce the cosmic ray background.

Quark Searches

These experiments are motivated by the quark model of matter, which is definitely confirmed in its basic aspects. The known quarks all have positive or negative electric charges which are one-third or two-thirds as large as that on the electron. A quark-antiquark pair makes up the meson families of particles, and triads of quarks make up the baryon families. No single quarks have as yet been observed and most theories indicate that quarks will not be observed separately. The quark searches indicated in Table D.1. are attempting to detect single quarks by attempting to find one-third or two-thirds electric charges (which have never been clearly detected to date). Most of the experiments are variations on the classic Millikan oil drop experiment which first directly measured the electric charge on individual electrons.

Neutrino and Tritium Experiments

The two UC Irvine neutrino experiments are intended to determine more about the fundamental properties of these elusive particles. The oscillation study is investigating whether or not one type of neutrino undergoes spontaneous transformation into another type of neutrino. This is expected to occur if the various types of neutrinos have different rest masses. To date all neutrino oscillation experiments have produced negative results, but the study of this phenomenon has only recently begun.

The tritium end-point study is a more direct measurement of the mass of the neutrino associated with nuclear beta decay. In the decay of tritium, the maximum energy of the emitted electrons is exactly equal to the difference in energy of the decaying nucleus before and after the decay, if the emitted neutrino has exactly zero rest mass. If the neutrino has a non-zero rest mass, the maximum electron energy will be slightly less. Some Russian experiments have claimed the measurement of a non-zero neutrino mass, but this has not yet been verified.

The question of the masses of the various neutrinos is not only of extreme importance in the theories of elementary particles and the field of high energy physics, but it is also of extreme importance in the theories of cosmology and the field of astrophysics. Much of the total mass of the universe may be "unseen", and the masses of neutrinos may play a vital role in this problem.

Cosmic Ray Studies

Four large experiments are being funded which are investigating various properties of the cosmic rays. The areas of study include the origins of cosmic rays, the location of point sources, the energy spectrum and the mass spectrum of the rays, the questions of neutrino oscillations and masses, and the properties of fundamental interactions at energies far above those made at the largest accelerators.

The largest of these is the DUMAND (Deep Underwater Muon and Neutrino Detector) experiment. The set up is essentially similar to the IMB and HPW detectors discussed under proton decay, but on a much larger scale. The water is in a deep ocean trough off the shores of Oahu and strings of photomultiplier tubes will observe the light generated by very high energy muons and other particles from neutrino interactions. This experiment was approved in its initial stages in 1983 and is now under construction.

New Experiments in FY 1984 and FY 1985

No major new experiments are expected in FY 1984 and FY 1985. As just mentioned, the DUMAND experiment is in a large apparatus-building phase. Also, the IMB and Soudan proton-decay experiments have been approved for major upgrades. The IMB detector will increase its light collection power by over threefold in order to detect more complicated modes of decay, and the Soudan "fine-grained" detector is being greatly increased in size.

E. HIGH ENERGY TECHNOLOGY

1. For the period FY 1981 - FY 1985, please provide, by DOE laboratory and by university, the estimated and actual funding levels for the High Energy Technology activity and its two major areas: accelerator R&D and experimental facility R&D.

Answer: The following table provides the requested data:

(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Argonne National Lab	$1,470	$1,000	$1,180	$1,275	$1,400
Accelerator R&D	745	500	500	575	600
Exp. Facility R&D	725	500	680	700	800
Brookhaven National Lab	19,050	22,560	23,040	22,210	21,200
Accelerator R&D	16,250	19,560	20,140	19,810	17,500
Exp. Facility R&D	2,800	3,000	2,900	2,400	3,700
Fermi Nat'l Accel Lab	22,980	23,140	31,032	28,700	26,000
Accelerator R&D	19,880	19,140	25,032	20,700	18,500
Exp. Facility R&D	3,100	4,000	6,000	8,000	7,500
Lawrence Berkeley Lab	4,800	4,880	6,795	8,180	8,500
Accelerator R&D	3,150	3,280	4,575	6,300	6,600
Exp. Facility R&D	1,650	1,600	2,200	1,880	1,900
Los Alamos National Lab	0	0	250	275	300
Accelerator R&D	0	0	250	275	300
Pacific Northwest Labs	0	0	301	0	0
Accelerator R&D	0	0	301	0	0
Stanford Linear Accel Ctr	9,330	13,230	24,300	15,000	16,700
Accelerator R&D	4,380	9,230	20,500	12,000	12,900
Exp. Facility R&D	4,950	4,000	3,800	3,000	3,800

University Contracts
Accelerator R&D
(Budget Authority in Thousands)

	FY 1981	FY 1982	FY 1983	Estimate FY 1984	Estimate FY 1985
Univ. of Ca., Irvine	$ 90	$ 360	$ 200	$ 0	$ 0
Univ. of Ca., Los Angeles	0	0	280	290	310
Univ. of Ca., Santa Barbara	0	0	0	50	0
Univ. of Ca., Santa Cruz	0	9	0	0	0
Univ. of Chicago	0	0	0	9	0
Clarkson College of Tech.	0	0	0	46	55
Univ. of Colorado	4	0	0	0	0
Columbia University	0	180	200	200	210
Cornell University	0	0	478	122	340
Georgia Inst. of Technology	52	62	65	70	75
Univ. of Illinois	0	0	0	100	110
Univ. of Maryland	178	405	472	980	1020
Massachusetts Inst. Tech.	0	0	45	60	70
Univ. of Michigan	0	0	0	81	90
NY City Univ.-City College	125	220	270	0	0
NY City Univ.-Staten Island	0	0	0	0	0
NY City Univ.-York College	75	85	90	0	0
Northwestern University	0	0	0	13	0
Univ. of Pittsburgh	129	0	0	0	0
Stanford Leland Jr. Univ.	56	130	0	0	0
Texas A&M	0	0	0	200	215
Univ. of Wisconsin	0	175	220	253	265

2. **What is the estimated distribution of funding, by performer, for the Superconducting Super Collider (SSC) R&D for FY 1984 and FY 1985?**

Answer: The table below gives the requested funding breakdown.

(Budget Authority in Millions)

	Estimate FY 1984	Estimate FY 1985
Brookhaven National Laboratory	$ 10.6	$ 9.0
Fermi National Accelerator Laboratory	4.0	4.0
Lawrence Berkeley Laboratory	2.0	2.0
Texas Consortium	1.6*	2.8
URA-SSC Interim Management	0.6**	1.5
Other	0.2	0.5
	$ 19.0	$ 20.0

* Funding for seven months only.
** URA SSC Interim Management activities did not begin until second half of the fiscal year.

3. **Please list the SSC ongoing and planned tasks for FY 1984 and FY 1985, as well as the planned funding levels for each.**

Answer: The following table provides planned funding levels for the Superconducting Super Collider ongoing and planned tasks:

(Budget Authority in Millions)

	Estimate FY 1984	Estimate FY 1985
Superconducting Magnet R&D (R&D cost reduction studies on four magnet concepts; fabrication and testing of small magnet models)	$ 14.7	$ 14.5
Systems Testing (Develop test bed for long string of magnets)	---	0.2
Industrial Participation	0.3	0.8
Systems Studies (Reference Designs Study; design, trade-off and optimization studies; and accelerator physics)	2.6	2.0
Cryogenics R&D	0.5	0.7
Other Technical Systems R&D (Vacuum, RF, instrumentation and control, support and alignment)	0.3	0.3
Interim Mgmt. & Administration (Integration & coordination of National SSC effort)	0.6	1.5
	$ 19.0	$ 20.0

4. Please describe briefly ongoing work (other than SSC activities) in accelerator R&D.

Answer: The DOE program in high energy physics supports an extensive advanced technology R&D effort as a necessary and essential support function to the basic research which is the primary programmatic mission. In the broadest sense, the high energy technology subprogram is responsible for providing the base of technological knowledge which underlies the highly specialized instrumentation used by the research physicists in their experiments. This instrumentation includes the accelerators and storage rings which are the sources of high energy particles; beam transport systems for delivering particles of the appropriate energy, momentum, and type to the experiments; experimental apparatus for detecting and recording the interactions which occur in the experiment; and dedicated, advanced data processing systems for analyzing the large volumes of data generated by experiments.

High energy technology R&D is supported in four general areas: improving and modifying existing apparatus; support of new construction; development of new apparatus for the next generation of experiments; and long-range new concept development. These correspond to a range of R&D from hard engineering application to theoretical and experimental studies in areas of classical physics and are carried out by a highly specialized group of people which may be best characterized as engineering physicists in that they must be expert in both the engineering and physics aspects of their respective technical disciplines. The ongoing work in accelerator R&D is best described by citing representative examples from each of the four areas.

Improvements and modifications to existing facilities are required to keep up with the rapidly changing needs of ongoing experiments and to ensure that the operation is made as cost effective as possible. A current project is the energy upgrade of the Stanford Linear Accelerator Center (SLAC) two-mile linac from 32 GeV to 50 GeV. To do this, it has been necessary to develop a new, high-powered klystron which operates at 50 megawatts peak power, almost 50 percent higher than the 35 megawatt tubes in current use. It was necessary for the program to pursue this development because no equivalent tube suitable for this application was available commercially. Other related R&D for the linac upgrade includes development of high precision beam positron sensors, improved electron sources, stronger magnetic focusing elements, and a totally automated instrumentation and control system. Projects similar in nature, but different in specifics, are underway to improve the injection efficiency of protons into the Fermilab Energy Saver and to provide for the accelaration of polarized protons at Brookhaven National Laboratory.

Construction of new facilities for high energy physics involves the practical application and development of very advanced technology. The technical components of high energy accelerator or storage ring construction projects generally represent the larger share of the construction cost; the conventional bricks and mortar, the smaller. High energy physics currently has three facility projects under construction, the Stanford Linear Collider (SLC) at SLAC and Tevatron Phases I and II at Fermilab.

Because a primary purpose of SLC is to develop and test a new accelerator concept, the supporting R&D is particularly sophisticated. One of several particularly challenging aspects of the SLC is the transport of 50 GeV beams of electrons and positrons from the end of the SLAC linac to the experimental interaction area. The two arc magnet transport systems which do this are each over a kilometer in length and must focus the individual particle beams down to a spot with a diameter of the order of microns (one millionth of a meter) and steer the two beams so that they collide. The theoretical study of second order magnetic achromats to achieve this highly precise transport and focusing has been a tour de force of the theory of charged particle beam transport.

Because high energy physics research explores the frontiers of knowledge and dynamically opens up new domains, development of the new technology which is essential for experimental progress must occur not only in response to the immediate needs of the research, but also in anticipation of the longer term needs. As a consequence, the DOE high energy physics program supports R&D to search for new inventions and concepts which will form the basis for tomorrow's research instrumentation and to reduce promising ideas, concepts, and inventions to practice. This latter activity, referred to as intermediate range R&D, is intended to provide working prototypes demonstrating the feasibility of new ideas in preparation for their actual application. A typical example is the development of phase-space cooling techniques for application to GeV energy antiproton beams. If successful, this will offer a significant potential improvement in the rate at which intense antiproton beams can be generated for use in proton-antiproton colliders, reducing operating costs and significantly improving operating flexibility. A program to develop a system to generate appropriate electron beams with which to do the cooling is currently underway at the National Electrostatic Corporation under a DOE Phase II Small Business Innovative Research (SBIR) contract. This work is proceeding in collaboration with the University of Wisconsin and Fermilab. Another example is the use of lasers to drive photocathodes in very high power radiofrequency amplifier tubes. Present studies, under way at SLAC, indicate that the electrical efficiency of such a device may be as high as 80 percent, promising, if successful, power savings of almost a factor of two over the present radiofrequency sources.

Long-range R&D relevant to the DOE high energy physics program is currently largely focused on activities highlighted in the extensive study conducted by the 1980 High Energy Physics Advisory Panel (HEPAP) Subpanel on Advanced Accelerator R&D. Long range R&D topics being pursued include collective effect accelerators, very high-field superconducting magnets, theory of nonlinear beam dynamics, use of intense laser beams to accelerate charged particles, phase-space cooling of beams, high peak power microwave sources, and development of very high gradient accelerator structures. A typical example of this work is research in progress at the University of California at Los Angeles to study the physics of using a laser beam to create coherent space charge oscillations in a plasma which, in turn, form very high accelerating potentials that can accelerate electrons to high energy in a very short distance, called the laser "beat wave" accelerator.

This concept, if feasible, could someday provide a totally new approach to very high gradient accelerators for possible application in some future linear collider.

5. **In June 1980, the HEPAP Subpanel on Accelerator R&D recommended that 4 percent of the HEP operating resources be devoted to long-range R&D. Where do we stand with respect to this recommendation? How much of the funded accelerator R&D is truly long range, and what types of activities are being supported?**

Answer: The 1980 High Energy Physics Advisory Panel (HEPAP) Subpanel on Accelerator R&D recommended that four percent of high energy physics operating resources be devoted to long range R&D which they defined as R&D not associated with a specific project. The present support of long-range accelerator R&D activities is considerably expanded from the levels which were reviewed by the 1980 HEPAP Subpanel on Advanced Accelerator R&D and is in line with the Subpanel's recommendations, using their definition of long range R&D. If truly long range accelerator R&D is taken to mean studies with the goal of initiating or developing totally new concepts and inventions, then about $6 million will be spent for such studies in FY 1984 and in FY 1985. There are now important studies in progress on the use of intense laser beams to accelerate charged particles, collective effect acceleration, nonlinear phenomenon in accelerators, phase-space cooling of particle beams, high peak power microwave sources, development of improved cryogenic refrigerator systems, and development of very high gradient accelerator structures. This work is carried out in universities and industry through contracts and grants administered by the DOE Division of High Energy Physics, in DOE-supported national laboratories, and in small businesses through the DOE Small Business Innovative Research (SBIR) program.

QUESTIONS CONCERNING THE DEPARTMENT OF ENERGY'S FY 1985 NUCLEAR PHYSICS BUDGET REQUEST

GENERAL

1. For the period FY 1981 - FY 1985, please identify, by subprogram and by facility, that portion of the Nuclear Physics funding going for the support of facilities, such as the Clinton P. Anderson Meson Facility at Los Alamos (LAMPF).

Answer:

Nuclear Physics Funding to
Accelerator Facility Operations
(B/A in thousands of dollars)

Subprogram	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Medium Energy					
National Facilities					
LBL Bevalac	$ 0	$ 0	$ 0	$ 1,000	$ 0
LANL LAMPF (1)	23,460	26,272	32,334	33,475	36,480
MIT Bates	4,162	4,603	4,738	5,360	5,750
SLAC Injector (2)	0	0	0	0	1,090
Subtotal	$27,622	$30,875	$37,072	$39,930	$43,320
Dedicated On-Campus Facilities					
None	$ 0	$ 0	$ 0	$ 0	$ 0
Subtotal	$ 0	$ 0	$ 0	$ 0	$ 0
Medium Energy Total	$27,622	$30,875	$37,072	$39,930	$43,320

(1) Includes Defense Programs support of LAMPF operations: $0 in FY 1981; $2,000,000 in FY 1982; $3,000,000 in FY 1983; $3,000,000 in FY 1984; and $0 in FY 1985.

(2) Operation of new off-axis injector at Stanford Linear Accelerator Center (a High Energy Physics facility) for basic nuclear research.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Heavy Ion					
National Facilities					
ANL Tandem/Linac	$ 1,275	$ 1,320	$ 1,302	$ 1,780	$ 1,855
BNL Double MP Tandem	1,580	1,708	1,251	1,500	1,560
LBL Bevalac (3)	13,565	14,503	14,474	16,270	17,625
LBL 88-Inch Cyclotron	1,180	1,261	1,260	1,435	1,495
ORNL Holifield	3,525	4,100	4,408	4,700	4,905
Subtotal	$21,125	$22,892	$22,695	$25,685	$27,440
Dedicated On-Campus Facilities					
Texas A&M Cyclotron	$ 135	$ 150	$ 200	$ 225	$ 230
U. of Washington Tandem	120	125	245	325	315
Yale MP Tandem	565	600	615	675	705
Subtotal	$ 820	$ 875	$ 1,060	$ 1,225	$ 1,250
Heavy Ion Total	$21,945	$23,767	$23,755	$26,910	$28,690

(3) Includes Life Sciences and Nuclear Medicine Applications support of Bevalac operations: $2,567,000 in FY 1981; $2,714,000 in FY 1982; and $0 in FY 1983, FY 1984, and FY 1985.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Low Energy					
National Facilities					
ANL Tandem/Linac	$ 283	$ 315	$ 307	$ 350	$ 365
LBL 88-Inch Cyclotron	572	575	528	541	565
ORNL Holifield	40	40	49	50	50
Subtotal	$ 895	$ 930	$ 884	$ 941	$ 980
Dedicated On-Campus Facilities					
U. of Colorado Cyclotron	$ 378	$ 200	$ 0	$ 0	$ 0
Duke Cyclograaff	343	435	510	655	685
Texas A&M Cyclotron	230	270	385	415	420
U. of Washington Tandem	275	300	365	390	405
U. of Wisconsin Tandem	125	100	0	0	0
Yale MP Tandem	205	274	345	365	380
Subtotal	$ 1,556	$ 1,579	$ 1,605	$ 1,825	$ 1,890
Low Energy Total	$ 2,451	$ 2,509	$ 2,489	$ 2,766	$ 2,870

Beam time for nonproprietary research at each of the National Facilities and the SLAC injector is available to all the Nation's scientists on the basis of scientific merit and technical feasibility of proposals reviewed by peer committees called program advisory committees. The program advisory committee for a given facility is appointed by and reports to the director of that facility. On the average 40% to 60% of National Facilities' beam time for research is made available to outside, university-based user scientists. Typically, such an outside university-based group plans experiments and fabricates detectors and other instrumentation at the home institution, executes and partially analyzes experiments at the National Facility, and completes analyses and publication of results at the home institution.

While each of the dedicated on-campus facilities has an important visitor program, these accelerators are operated principally for the research use of the host university's faculty, postdocs, and graduate students. The Duke Cyclograaff serves a consortium of three universities (Duke University, University of North Carolina, and North Carolina State University) called the Triangle Universities Nuclear Laboratory.

Facility Operations includes costs of delivering beam for use by research scientists. It includes all costs of accelerator operations (including electric power) and maintenance and includes all costs of operation and maintenance of permanently installed equipment such as beam lines, beam dumps, and magnetic spectrometers. Facility Operations does not include cost of setup and execution of individual experiments, support of in-house research, support of outside user research, or cost of Plant and Capital additions to the accelerator laboratory.

2. **For the period FY 1981 - FY 1985, please provide, by Nuclear Physics subprogram and by DOE laboratory, the amount of Nuclear Physics funding going to DOE laboratories.**

Answer:

Nuclear Physics Funding
to National Laboratories
(B/A in thousands of dollars)

Subprogram	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Medium Energy					
ANL	$ 1,335	$ 1,817	$ 2,185	$ 2,250	$ 2,340
BNL	1,080	968	850	1,145	1,585
INEL	0	-11	0	0	0
LBL	-37	- 1	0	1,000	0
LLNL	35	65	70	85	120
LANL (1)	30,935	34,497	40,352	41,330	43,915
ORNL	85	44	0	150	0
SLAC	0	0	0	95	1,090
	$33,433	$37,379	$43,457	$46,055	$49,050

(1) Includes Defense Programs support of LAMPF operations: $0 in FY 1981; $2,000,000 in FY 1982; $3,000,000 in FY 1983; $3,000,000 in FY 1984; and $0 in FY 1985.

Heavy Ion	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
ANL	$ 3,030	$ 3,351	$ 3,150	$ 4,080	$ 4,235
BNL	3,115	3,400	2,300	2,755	2,870
INEL	50	55	- 8	0	0
LBL(2)	20,215	21,984	21,167	24,885	26,755
LLNL	0	0	39	0	0
LANL	123	110	145	150	155
ORNL	6,115	7,075	7,200	7,965	8,295
Sandia	-23	0	0	0	0
	$32,625	$35,975	$33,993	$39,835	$42,310

(2) Includes Life Sciences and Nuclear Medicine Applications support of Bevalac operations: $2,567,000 in FY 1981; $2,714,000 in FY 1982; and $0 in FY 1983, FY 1984, and FY 1985.

Nuclear Theory	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Ames	$ 180	$ 150	$ 0	$ 0	$ 0
ANL	840	750	825	860	895
BNL	544	600	630	640	705
LBL	690	701	730	805	840
LLNL	50	-10	0	1	0
LANL	801	825	870	990	925
ORNL	590	621	680	695	725
	$ 3,695	$ 3,637	$ 3,735	$ 3,991	$ 4,090

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Low Energy					
Ames	$ 200	$ 185	$ 190	$ 215	$ 220
ANL	2,095	2,015	2,055	2,100	2,205
BNL	2,012	2,430	2,575	2,400	2,605
INEL	45	90	0	0	0
LBL	1,225	1,085	1,700	1,645	1,715
LLNL	150	150	140	155	150
LANL	230	217	360	465	440
ORNL	810	990	792	875	880
Sandia	6	0	0	0	0
	$ 6,773	$ 7,162	$ 7,812	$ 7,855	$ 8,215

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Capital Equipment					
ANL	$ 850	$ 970	$ 1,420	$ 1,745	$ 1,850
BNL	785	645	670	900	2,850
LBL	2,845	2,925	3,660	3,515	3,900
LANL	2,120	2,320	2,620	2,765	2,780
ORNL	1,090	1,175	990	1,290	1,250
	$ 7,670	$ 8,035	$ 9,360	$10,215	$12,630

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Construction					
ANL	$ 0	$ 4,000	$ 3,700	$ 0	$ 660
BNL	300	0	0	0	5,300
LBL	2,600	1,850	2,600	2,200	3,900
LANL	1,000	1,100	285	1,000	2,050
ORNL	200	450	0	0	0
SLAC	0	0	0	1,650	0
	$ 4,100	$ 7,400	$ 6,585	$ 4,850	$11,910

3. For the period FY 1981 - FY 1985, please provide, by Nuclear Physics subprogram and by institution, the amount of Nuclear Physics funding going to university researchers.

Answer:

Nuclear Physics Funding
to University Researchers
(B/A in thousands of dollars)

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Subprogram					
Medium Energy					
Abilene Christian U.	$ 15	$ 34	$ 46	$ 50	$ 54
U. of California-Berkeley	170	180	195	200	215
U. of California-Los Angeles	490	480	704	560	595
California Inst. of Tech.	510	550	560	670	710
Carnegie-Mellon U.	433	646	534	573	575
Case Western Reserve U.	0	-63	0	0	0
U. of Chicago	196	230	169	0	0
Clark U.	0	0	30	70	85
U. of Colorado	165	305	300	340	380

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Harvard U.	24	28	30	30	35
U. of Houston	195	225	270	275	285
U. of Indiana	50	5	3	0	0
Johns Hopkins U.	105	125	125	120	0
Mass. Inst. of Tech.	5,685	6,333	6,500	7,630	8,195
U. of Massachusetts	170	200	300	180	230
Michigan State U.	100	0	0	0	0
U. of Minnesota	195	235	255	315	325
U. of New Hampshire	125	175	215	315	325
New Mexico State U.	95	105	133	132	140
U. of New Mexico	230	260	290	324	345
City College of New York	20	20	25	25	20
North Carolina State U.	0	-3	0	0	0
Northwestern U.	140	160	180	205	220
Ohio State U.	0	170	0	0	0
U. of Ohio	67	0	0	0	0
U. of Pennsylvania	314	200	230	200	0
Princeton U.	45	40	33	39	0
Purdue U.	200	201	247	197	170
Rice U.	395	460	480	450	425
U. of Rochester	55	62	68	0	0
Southeastern Univ. Res. Assoc.	0	0	0	2,000	5,000
Syracuse U.	0	0	0	80	130
Temple U.	186	215	270	330	400
Texas A&M U.	165	180	212	218	215
U. of Texas at Austin	256	341	330	436	470
Valparaiso U.	0	0	0	83	90
Vassar College	32	35	38	34	0
Virginia Polytechnic Inst.	53	0	0	100	100
U. of Virginia	435	506	600	655	690
U. of Washington-Seattle	135	115	125	105	65
U. of Wisconsin	30	0	0	0	0
U. of Wyoming	45	48	50	55	58
Yale U.	400	500	500	550	570
	$11,926	$13,303	$14,047	$17,481	$21,062

Heavy Ion	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
U. of California-Davis	$ 100	$ 16	$ 0	$ 0	$ 0
U. of California-Los Angeles	145	160	20	210	220
U. of California-Riverside	222	239	258	115	280
Carnegie-Mellon U.	125	145	152	140	150
U. of Florida	0	80	0	160	100
Georgia Inst. of Tech.	95	100	110	118	130
Georgia State U.	32	49	39	42	45
U. of Indiana	129	141	148	156	165
Johns Hopkins U.	105	125	125	140	160
U. of Kansas	55	51	51	59	62
Louisiana State U.	155	179	184	274	201
U. of Maryland	59	90	90	95	100
Massachusetts Inst. of Tech.	630	680	580	500	645
Michigan State U.	0	10	0	7	0
U. of Minnesota	20	0	34	106	90

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
St. U. of New York-Stony Brook	141	163	174	180	190
Notre Dame U.	0	0	0	200	0
Oak Ridge Assoc. Univ.	315	345	345	345	380
Oregon State U.	39	50	58	65	70
Purdue U.	234	116	127	153	160
U. of Rochester	257	263	290	310	310
U. of South Carolina	30	38	47	50	50
Stanford U.	0	0	76	103	105
Tennessee Tech. U.	38	77	83	119	95
U. of Tennessee-Knoxville	170	173	190	200	210
Texas A&M U.	396	350	350	400	390
Vanderbilt U.	165	200	191	210	220
U. of Washington-Seattle	530	575	550	725	675
Washington U.	185	230	445	231	240
U. of Wisconsin	-16	0	0	0	0
Yale U.	1,125	1,200	1,205	1,350	1,410
	$ 5,481	$ 5,845	$ 5,922	$ 6,763	$ 6,853

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Nuclear Theory					
Boston U.	$ 31	$ 29	$ 34	$ 0	$ 0
Brown U.	99	88	95	102	111
California St. U.-Northridge	0	23	25	40	42
U. of California-Santa Cruz	0	0	2	0	0
U. of Colorado	108	120	135	133	139
U. of Connecticut	0	23	0	0	0
Duke U.	0	0	15	55	58
Florida State U.	85	93	100	106	110
George Washington U.	50	60	65	75	79
U. of Indiana	0	110	120	135	142
Iowa State U.	0	29	68	77	81
U. of Iowa	38	58	64	70	74
U. of Kentucky	0	79	0	47	49
U. of Maryland	440	448	493	680	557
Massachusetts Inst. of Tech.	680	750	835	885	875
Michigan State U.	0	90	95	40	0
U. of Minnesota	115	125	145	157	170
St. U. of New York-Stony Brook	415	545	792	690	723
New York U.	71	76	84	95	100
North Carolina State U.	32	45	50	53	56
U. of Ohio	0	65	70	76	80
Oregon State U.	15	23	4	55	58
U. of Pennsylvania	0	0	0	83	135
Rensselaer Polytechnic Inst.	55	40	26	40	42
U. of Rochester	175	191	206	220	230
Texas A&M U.	120	130	0	0	0
U. of Texas	155	134	143	150	130
Vanderbilt U.	0	0	0	20	32
Virginia Polytechnic Inst.	67	130	140	73	87
U. of Washington-Seattle	311	340	375	435	500
Yale U.	230	210	230	270	280
	$ 3,292	$ 4,054	$ 4,411	$ 4,862	$ 4,940

Low Energy	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Clark U.	$ 58	$ 58	$ 60	$ 58	$ 65
U. of Colorado	719	400	0	0	0
Cornell U.	67	55	36	44	0
Duke U.	710	945	1,075	1,445	1,510
Florida State U.	0	3	0	0	0
Georgia Inst. of Tech.	43	43	50	42	45
U. of Indiana	-1	0	0	0	0
Iowa State U.	110	0	50	41	46
U. of Kentucky	60	0	-3	0	0
U. of Maryland	65	9	80	85	90
Massachusetts Inst. of Tech.	20	-40	0	0	0
Middle Tennessee State U.	35	32	35	0	0
City U. of New York-Brooklyn	142	153	92	91	93
North Carolina State U.	75	75	80	120	125
U. of North Carolina	170	191	210	225	235
North Texas State U.	0	8	0	0	0
U. of Oklahoma	0	45	36	39	0
Texas A&M U.	460	600	720	780	750
U. of Washington-Seattle	735	1,339	968	1,035	1,075
U. of Wisconsin	723	514	171	222	185
Yale U.	500	659	695	735	765
	$ 4,691	$ 5,089	$ 4,355	$ 4,962	$ 4,984

Capital Equipment	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Massachusetts Inst. of Tech.	$ 1,900	$ 1,400	$ 1,000	$ 1,065	$ 1,050
Oak Ridge Assoc. Univ.	50	50	50	20	20
Yale U.	250	25	0	0	0
	$ 2,200	$ 1,475	$ 1,050	$ 1,085	$ 1,070

Construction					
Massachusetts Inst. of Tech.	$ 300	$ 100	$ 1,115	$ 850	$ 390
Michigan State U.	6,900	4,500	0	0	0
U. of Washington-Seattle	0	0	0	4,000	4,000
Yale U.	0	0	0	4,000	7,000
	$ 7,200	$ 4,600	$ 1,115	$ 8,850	$11,390

4. For the period FY 1981 - FY 1985, please provide, by Nuclear Physics subprogram and by company, actual and estimated funding going to industry.

Answer:

Nuclear Physics Funding
to Industry
(B/A in thousands of dollars)

Subprogram	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Medium Energy					
Ebon Research Systems	$ 13	$ 0	$ 0	$ 0	$ 0
McLeod Corp.	9	0	0	0	0
W. J. Schafer Assoc., Inc.	0	96	0	0	0
Technassociates, Inc.	-11	0	0	0	0
Small Business Innov. Res.	0	0	(110)*	366	702**
	$ 11	$ 96	$ 0	$ 366	$ 702
Heavy Ion					
Ebon Research Systems	$ 14	$ 0	$ 0	$ 0	$ 0
Hayes, Seay, Mattern & Mattern	6	0	0	0	0
Small Business Innov. Res.	0	0	(90)*	227**	442**
	$ 20	$ 0	$ 0	$ 227	$ 442
Nuclear Theory					
Small Business Innov. Res.	0	0	0	54**	95**
	$ 0	$ 0	$ 0	$ 54	$ 95
Low Energy					
Small Business Innov. Res.	0	0	0	133**	196**
	$ 0	$ 0	$ 0	$ 133	$ 196

* In FY 1983, Small Business Innovation Research funds were reprogrammed from Nuclear Physics and are not being reported as part of Nuclear Physics budget total.

** Recipients of FY 1984 and FY 1985 Small Business Innovation Research awards have not yet been selected.

5. **For the period FY 1981 - FY 1985, please provide, by Nuclear Physics subprogram and by foreign institution, actual and estimated funding going to support Nuclear Physics research at foreign institutions.**

Answer: The Nuclear Physics program provides no direct funding to any foreign institution. Funding is provided, however, to support scientists from United States universities and DOE laboratories in carrying out experimental or theoretical research at foreign institutions. Estimates of the amounts provided for significant activities of this type are contained in the following table:

Nuclear Physics Funding to
Research at Foreign Institutions
(B/A in thousands of dollars)

Institution (Country)	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Subprogram					
Medium Energy					
CERN-ISR and LEAR (Switz.)	$ 400	500	600	700	850
Gosgen Power Reactor (Switz.)	500	450	400	300	50
Mainz Electron Microtron (W. Germ.)	0	0	150	200	300
Saclay-Saturn & ALS (France)	200	250	250	300	350
SIN (Switz.)	200	250	250	250	300
TRIUMF (Canada)	300	300	300	300	300
Other*	150	150	150	150	150
	$ 1,750	$ 1,900	$ 2,100	$ 2,200	$ 2,300
Heavy Ion					
CERN-ISR, LEAR & SPS (Switz.)	$ 200	$ 200	$ 300	$ 500	$ 900
Darmstadt-GSI (W. Germ.)	100	100	150	150	200
Other**	100	100	100	100	100
	$ 400	$ 400	$ 550	$ 750	$ 1,200

* Includes Bonn (W. Germany), Amsterdam-NIKHEF (Netherlands), and Osaka (Japan).

** Includes Copenhagen-Bohr Institute (Denmark), Heidelberg-Planck Institute (W. Germany), and Caen-GANIL (France).

Institution (Country)	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Nuclear Theory					
Copenhagen-Bohr Inst. (Den.)	$	$	$	$	$
Oxford/Daresbury (UK)	Totals are estimated; information by institution is not available.				
CERN & SIN (Switz.)					
Other (W. Europe & Austral.)					
	$ 300	$ 300	$ 300	$ 300	$ 300
Low Energy					
Grenoble-ILL (France)	$	$	$	$	$
Saclay (France)					
BNM (Belgium)	Totals are estimated; information by institution is not available.				
JAERI (Japan)					
IAE (PRC)					
Other (W. Europe)					
	$ 50	$ 50	$ 50	$ 50	$ 50

6. For the period FY 1981 - FY 1985, please provide, by Nuclear Physics subprogram and by nation, actual and estimated funding or other support received from other nations for Nuclear Physics research in the U.S.

Answer: No direct support is received from other nations for nuclear physics research in the United States. Some other nations--most notably West Germany and Japan--have very active research programs using United States facilities.

These activities often involve considerable expenditure of funds by those countries for major pieces of equipment as well as salaries and travel costs for their participants, but as with the use of foreign facilities by United States scientists, no direct payments are made to the host institution by the user. Though accurate information is not available to us on their nuclear physics research activities in the United States, we estimate that the total amount is not dramatically different from that spent by us for nuclear physics research at foreign institutions.

7. **How much of the FY 1985 Nuclear Physics budget request is for support of programs formerly funded by the DOE Nuclear Program or by any other DOE program?**

Answer: In FY 1982, FY 1983, and FY 1984, Defense Programs provided $2,000,000; $3,000,000; and $3,000,000 respectively for LAMPF facility operations. The Department's FY 1985 Budget Request provides for no Defense Programs support of LAMPF operations. In FY 1981 and FY 1982, Life Sciences and Nuclear Medicine Applications provided $2,567,000 and $2,714,000 respectively for Bevalac operations. Beginning with FY 1983 and by mutual agreement, Nuclear Physics has assumed responsibility for budgeting for all Bevalac facility operations including operations for biomedical research. None of the FY 1985 Nuclear Physics budget request is for support of programs formerly funded by the DOE Nuclear Program.

8. **What have been the major accomplishments of this program over the past five years?**

Answer: The Department of Energy's Nuclear Physics program is the major Federal program concerned with studies of the fundamental interactions, properties, and structure of atomic nuclei. Major efforts are concerned with very precise determinations of nuclear structure and the fundamental forces between the nucleons in the nucleus and with studies of the behavior of nuclei under extremes of temperature, density, pressure, and rotational frequency. The past five years have been particularly fruitful ones in several important areas of the program. There has developed a large body of information and understanding on the properties of nuclear states with large angular momentum (high spin states). New forms of nuclear collective motion have been found in this period. There has been significant theoretical progress made in this period towards understanding the microscopic structure of collective nuclear behavior at both low and high spins. With new higher energy heavy ion accelerators coming in line in this period, it has been possible to study what happens when two nuclei literally tear each other apart as they collide. In such experiments, it is found that pieces of nuclear matter are formed that are far hotter and denser than normal nuclear matter. Studies of this matter show us how nuclear matter compresses and then cools down. Brief descriptions of specific developments follow.

New Forms of Collective Motion

Physicists at the Clinton P. Anderson Meson Physics Facility (LAMPF) observed an isovector monopole mode of nuclear collective motion wherein neutrons (protons) move as a sphere breathing in and out. In the isovector monopole mode, as the protons breathe in, the neutrons breathe out and vice versa. Detailed studies of these monopole modes tell us how nuclei behave when compressed.

Each nucleon in a nucleus spins around an axis through its center. A new collective mode has been found in many nuclei over a broad mass range where the axes of rotation of nucleons near the surface of the nucleus are aligned. The properties of these spin-aligned or Gamow-Teller states show that the traditional model of nuclei built from neutrons and protons must be modified to include excited states of the nucleons.

The force between nucleons in a nucleus at all but the shortest distances can be described as the exchange of a pi meson (pion) between pairs of nucleons. In a series of experiments by a collaboration between scientists at several DOE laboratories, it has been observed that pions are produced during the collision between two heavy ions, where the energy of the heavy ion projectile is so low that no single collision between a nucleon in each of the colliding nuclei can possibly create a pion. The only possible interpretation is that several nucleons in each nucleus cooperate to provide the energy necessary to produce a pion.

Increased sophistication of accelerator and instrumentation technology at the Bates Linear Accelerator Center at Massachusetts Institute of Technology (MIT) now allow tests of unprecedented precision of the familiar collective model of low energy nuclear states. Analysis of inelastic electron scattering experiments on ^{154}Gd have clearly demonstrated that there are three distinct classes of collective states in this one nucleus. In one, the nucleus rotates as a football, and in the other two classes, the nucleus vibrates in two distinct modes around this football shape. This is the first clear demonstration of the simultaneous existence of these three collective modes in one nucleus.

Nuclei Under Extreme Stress

With the now available heavy ion accelerators, it is possible to form nuclei with very high angular momentum. In light ion induced reactions, typically, nuclei with 10 units of angular momentum are formed. With heavy ions, nuclei with 40 units of angular momentum have now been produced. It is now possible to trace out the shape of the nucleus with increasing rotational frequency. At low spins, the nucleus usually has a football shape. At intermediate spins, Coriolis forces become strong, and the net effect is the nucleus behaves as if it were made of two fluids--a central core fluid which continues to rotate as a football and a second fluid which flows around the circular equator of the football. At the highest spins observed to date, the rotational forces result in the nucleus assuming a pancake shape.

In high energy heavy ion experiments at the Bevalac facility at Berkeley, fragmentation experiments have been used to produce new nuclei, e.g., ^{62}Ca and ^{35}Na. In naturally existing nuclei, for all but the very lightest nuclei, the ratio of neutrons to protons is less than about 1.5. In the new isotopes, this ratio is greater than two. No known theory of nuclear masses has successfully accounted for the masses of these exotic nuclei.

New Tests of the Fundamental Forces of Nature

A particularly vital area of physics research is the development of the Grand Unification Theories of the weak, strong, and electromagnetic forces. Some of the most stringent tests of these theories could be made by studying the scattering of electrons and neutrinos. A major problem is that the electron-neutrino interaction is so weak that it is almost impossible to observe such scatterings. Scientists at the LAMPF facility have recently observed, for the first time anywhere, the scattering of neutrinos from electrons.

During the collision of two uranium nuclei, a composite "nucleus" with Z=184 can be formed. The existence of such a large charge concentration creates strong electromagnetic forces, and the possibility of tests of Quantum Electro-Dynamics is far more stringent than previously possible. One prediction is that, in such a strong field, the normally filled positron vacuum would break down and there would be a spontaneous emission of positrons. In a series of experiments on the scattering of uranium nuclei from a uranium target, the spontaneous production of positrons has been observed. The results suggest that the two uranium nuclei coalesce for a far longer time than present nuclear theories would predict.

New Capabilities

In this same five-year period, when many significant physics results have been obtained, there have also been a number of significant achievements in the development of new facilities which will provide the state-of-the-art tools needed for nuclear physics research in the next five years.

At the Lawrence Berkeley Laboratory, the Bevalac accelerator was modified to produce beams of uranium ions (238 atomic mass units) with energies up to 1 GeV/atomic mass unit. This is by far the highest energy uranium beam in the world. The beams will be used in the early experiments to create intense concentrations of mass and energy out of which new forms of nuclear matter are possible or even likely. The beams have already been used to produce uranium ions where all but one or two of the orbital electrons have been stripped away. With such highly stripped ions, experimental tests are possible which will test the fundamental quantum electrodynamics (QED) theory to an accuracy far beyond that presently available.

At the Argonne National Laboratory, the first superconducting heavy ion linear accelerator was placed in operation as part of the ATLAS facility at that Laboratory. The machine will provide beams with quality comparable to those from electrostatic accelerators and will offer the economy of superconductivity. The niobium technology used in this accelerator should have many applications where superconductivity technology is used for radiofrequency cavities.

As part of the Holifield Heavy Ion Research Facility, scientists from Washington University at St. Louis and the Oak Ridge National Laboratory have developed the Spin Spectrometer, a 4-pi gamma ray detector constructed from 72 individual NaI detectors. The detector can detect individually all the gamma rays produced in high-multiplicity events, provide the necessary details on the decay of high spin systems, and thus provide new insights into the behavior of nuclei with high angular momentum. Spectrometers similar to the spin spectrometer are now under construction at most of the heavy ion accelerator laboratories in the world.

An operational capability of 1.2 milliampere average current has been demonstrated at the Clinton P. Anderson Meson Physics Facility (LAMPF), 20% above the design capability. LAMPF now generates higher intensity than the sum intensities of all the world's proton accelerators which operate above the energy threshold for pion production.

9. For the period FY 1981 - FY 1985, how much funding has this program provided and is estimated to provide for the R&D of experimental devices/apparatus?

Answer: The estimated funding for the research and development (R&D) of experimental devices/apparatus, excluding funds for accelerator R&D and Small Business Innovation Research, is $5 million (FY 1981), $6 million (FY 1982), $6 million (FY 1983), $6 million (FY 1984), and $7 million (FY 1985).

10. How does the research funded by the Nuclear Physics program differ, complement, supplement, or overlap nuclear physics research funded by any other parts of DOE, as well as by other agencies such as the National Science Foundation.

Answer: The Nuclear Physics program is the only DOE program whose goal is an understanding of the interactions, properties, and structures of atomic nuclei and nuclear matter at the most elementary level possible. Other DOE programs/offices, such as Defense Programs, Nuclear Energy, Fusion Energy, Life Sciences and Nuclear Medicine Applications, and Basic Energy Sciences have specific need for specific nuclear information. They directly support nuclear measurements to meet their particular programmatic requirements. The Nuclear Physics program complements and supplements these other DOE programs by provision of a broad and supportive base of knowledge, techniques, instrumentation, and trained manpower.

Also, the Nuclear Physics program provides unique beams to these programs and offices. For example, LAMPF provides proton beam for use by Defense Programs and Basic Energy Sciences at the Weapons Neutron Research facility; Bevalac provides unique heavy ion beams for Life Sciences and Nuclear Medicine Applications; and SuperHILAC, Holifield, ANL Tandem/Linac, and BNL Double MP each provide ion beams for use by Basic Energy Sciences atomic physics research.

Approximately 80% of the total Federal support of basic nuclear research is provided through the Nuclear Physics program; almost all of the remaining 20% is provided by the National Science Foundation. Thus, the Department of Energy has a unique responsibility for this important area of basic science and its role in high technology. The DOE Nuclear Physics Program supports the large and complex national accelerator facilities (such as LAMPF, Bevalac, Holifield, and Bates) which are essential to frontier basic nuclear research. Whereas, the NSF program is much more oriented toward dedicated on-campus facilities. As discussed below, the DOE and NSF programs are closely coordinated.

Long range planning, scientific community input, and coordination of Department of Energy work with National Science Foundation (NSF) activities take place through a variety of channels. The most important of these channels are external and internal review of specific research areas, frequent staff contact with counterparts at NSF, and the work of the DOE/NSF Nuclear Science Advisory Committee (NSAC). In cooperation with the Department of Energy and the National Science Foundation, NSAC has developed a long range plan for basic nuclear research in the United States--"A Long Range Plan for Nuclear Science" (December 1983). This long range plan is based upon a comprehensive review of scientific advances and opportunities which have emerged since development of the previous long range plan--"A Long Range Plan for Nuclear Science" (December 1979).

11. What types of formal and informal advisory groups are employed to assure that the program is of high quality and coordinated with the research carried out at other agencies? If any formal advisory groups exist, please define the role of each, and provide a listing of the current membership.

Answer: Several types of formal and informal advisory groups are employed to assure that the program is of high quality and coordinated with the research carried out at other agencies. The principal advisory group, charged with general overview of the United States effort in basic nuclear research, is the DOE/NSF Nuclear Science Advisory Committee (NSAC). This is a Federally chartered advisory committee, serving both the Department of Energy and the National Science Foundation. The current membership is as follows:

- Professor Gordon A. Baym, University of Illinois
- Professor D. Allan Bromley, Yale University
- Professor Frank Calaprice, Princeton University
- Professor Herbert H. Chen, University of California at Irvine
- Professor Douglas Cline, University of Rochester
- Dr. Karl A. Erb, Oak Ridge National Laboratory
- Dr. Hermann A. Grunder, Lawrence Berkeley Laboratory
- Dr. Ole Hansen, Brookhaven National Laboratory
- Dr. Cyrus M. Hoffman, Los Alamos National Laboratory
- Professor Arthur K. Kerman, Massachusetts Institute of Technology
- Professor Malcolm H. Macfarlane, Indiana University
- Professor Philip B. Roos, University of Maryland
- Dr. John P. Schiffer, Argonne National Laboratory (Chairman)
- Dr. Ingo Sick, University of Basel
- Dr. Erich W. Vogt, University of British Columbia

NSAC provides, on a continuing basis, advice to both DOE and NSF on scientific priorities within the field of basic nuclear research. Basic nuclear research is understood to encompass experimental and theoretical investigations of the fundamental interactions, properties, and structure of atomic nuclei. NSAC activities include assessment of and recommendations concerning: (a) objectives, directions and development, and future frontiers of the field of basic nuclear science; (b) adequacy of present facilities and the need and relative priority for new facilities; (c) facility and instrument development programs needed to advance the field; (d) institutional balance of support for optimized scientific productivity and training of nuclear scientists; (e) relationships of basic nuclear science with other fields of science. In addition, NSAC conducts specialized studies when requested by the agencies. In cooperation with the DOE and NSF, NSAC has developed a "Long Range Plan for Nuclear Science" (December 1983). This Plan is based upon a comprehensive review of scientific advances and opportunities which have emerged since development of the previous Plan in 1979.

At each of Nuclear Physics's national accelerator facilities, beam time for nonproprietary research is available to all the Nation's scientists on the basis of scientific merit and technical feasibility of proposals reviewed by peer committees called program advisory committees. The program advisory committee for a given facility is appointed by and reports to the director of that facility.

12. What is the current rate of Ph.D. production in the nuclear physics?

Answer: The rate of Ph.D. production in the United States in nuclear physics has been 60-80 per year since 1980.

13. What is the average cost to produce a Ph.D. in this field?

Answer: We estimate the cost to the Nuclear Physics program to produce a typical Ph.D. in nuclear physics to be approximately $100,000 to $200,000.

An exact statement of cost depends sensitively upon the accounting criteria used. For example, if cost of providing beam at the national accelerator facilities and/or cost of capital improvements at the national facilities were included, then a figure much greater than $200,000 would be obtained. We have not included such costs. However, we have included estimates of minor instrumentation costs necessary for thesis research--that is, costs of equipment specific to a given experiment rather than costs of more general equipment which will be used by many researchers. Thus, you will find a grouping of experimental Ph.D.'s at the high end of the scale and theoretical Ph.D.'s at the low end.

14. Has the number of nuclear physics researchers supported by this program been increasing, stable, or decreasing over the past five years? What change will occur given the FY 1985 budget request?

Answer: Federal support in constant year dollars for basic research has declined in recent years, especially when inflation rates for operation of accelerator facilities are taken into account. In a field such as nuclear physics, the costs of the high technology needed to do effective research is increasing at a greater rate than the average for the rest of the economy. The net effect has been some reduction over the past five years in the number of scientists in basic nuclear research. The FY 1985 budget request for the Nuclear Physics program implies a cut of five percent in the level of research activities which indicates again a reduction in the number of researchers.

15. What is the average annual cost per year to this program to support a nuclear physics researcher?

Answer: In FY 1981 (the latest year for which accurate information is available), there were 1,268 nuclear physics researchers supported by the DOE Nuclear Physics program at a cost of $87,000 per nuclear physics researcher. At the present time, the average annual operating cost per full time equivalent (FTE) is estimated to be $110,000.

16. How much has the Nuclear Physics Program contributed to the support of DOE's Small Business Innovative Research (SBIR) Program for FY 1983? How much is estimated for FY 1984 and FY 1985? How was this assessment determined?

Answer: In FY 1983, $200,000 was reprogrammed from Nuclear Physics for awards under the Small Business Innovation Research (SBIR) program. In FY 1984 and FY 1985, SBIR awards from Nuclear Physics appropriations are estimated at $780,000 and $1,435,000, respectively. These assessments are determined in accordance with Public Law 97-219, the Small Business Innovation Development Act of 1982.

A. HOLIFIELD TABLES

1. **The January 31, 1984 "Holifield Tables" indicate that the IRB Fiscal Year 1985 budget request for the Nuclear Physics (NP) Program totalled $201,000,000, including $151,500,000 for operating expenses and 49,500,000 for plant and capital equipment (PACE). According to these Tables, the Department's FY 1985 submission to OMB for the program totalled $196,000,000, including $150,000,000 for operating expenses and $46,000,000 for PACE. What are the specific differences between these two budgets?**

Answer: Specific differences between the Nuclear Physics IRB and Nuclear Physics OMB budget requests are given below:

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1985 IRB Request	FY 1985 OMB Request	Change
Operating Expenses	$151,500	$150,000	-$ 1,500
Capital Equipment	13,000	13,000	0
Construction	36,500	33,000	- 3,500
TOTAL	$201,000	$196,000	-$ 5,000

Operating Expenses

- The $1,500,000 reduction in the request for Operating Expenses would have reduced the ability of accelerator facilities to keep pace with cost escalation. Because LAMPF is the NP facility most sensitive to electric power rate increases, LAMPF would have been the most heavily impacted. LAMPF operations would have been reduced from 3000 beam hours for research (IRB Request) to 2800 hours (OMB Request).

Plant and Capital Equipment

- A $500,000 reduction in Accelerator Improvements and Modifications required dropping of a subproject to upgrade the Brookhaven Double MP by addition of an electrostatic intershield to the second stage tandem.

- A $1,000,000 increase in General Plant Projects was part of a Departmental initiative to improve plant maintenance at the national laboratories.

- A $4,000,000 reduction (from $19,000,000 to $15,000,000) in the Continuous Electron Beam Accelerator Facility (CEBAF) construction project would have required stretchout from the "fast track" schedule envisioned in the IRB Request.

2. **As noted in question 1 above, the Holifield Tables indicated that the OMB FY 1985 budget request for the NP program totalled $196,000,000 including $150,000,000 for operating expenses and $46,000,000 for PACE. The FY 1985 Congressional request for NP totalled $183,600,000, including $144,600,000 for operating expenses and $39,000,000 for PACE. What are the specific differences between these two budgets?**

Answer: Specific differences between the Nuclear Physics OMB and Nuclear Physics Congressional budget requests are given below:

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1985 OMB Request	FY 1985 Cong. Request	Change
Operating Expenses	$150,000	$144,600	-$ 5,400
Capital Equipment	13,000	13,700	+ 700
Construction	33,000	25,300	- 7,700
TOTAL	$196,000	$183,600	-$12,400

Operating Expenses

- The $5,400,000 reduction in the request for Operating Expenses required an overall 10% reduction in NP accelerator utilization when compared to FY 1984 operating levels. LAMPF was more heavily impacted than the NP program norm because of relatively high escalation rates projected by LANL for FY 1985. LAMPF beam hours for research in FY 1985 were reduced from 2800 hours (OMB Request) to 2450 hours (Congressional Request). SLAC injector operations for basic nuclear research were reduced by 50%, from eight weeks (OMB Request) to four weeks (Congressional Request).

Plant and Capital Equipment

- An increase of $7,000,000 was provided in the Congressional Request over the OMB Request for the BNL Transfer Line project (+$5,300,000 in Construction and +$1,700,000 in Capital Equipment).
- The $14,100,000 decrease ($1,100,000 in Capital Equipment and $13,000,000 in Construction) in the Continuous Electron Beam Accelerator Facility (CEBAF) project limited CEBAF activities in FY 1985 to architect-engineering work, detailed design beyond conceptual design, and preliminary site work.
- There was a $100,000 increase in Capital Equipment for detectors at Bevalac.

3. **Given the information in questions 1 and 2 above, what are the specific differences between the Department's FY 1985 IRB and the Congressional Request budgets for NP?**

Answer: Specific differences between the Nuclear Physics IRB and Nuclear Physics Congressional budget requests are given below:

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1985 IRB Request	FY 1985 Cong. Request	Change
Operating Expenses	$151,500	$144,600	-$ 6,900
Capital Equipment	13,000	13,700	+ 700
Construction	36,500	25,300	- 11,200
TOTAL	$201,000	$183,600	-$17,400

Operating Expenses

- The $6,900,000 reduction in the request for Operating Expenses required an overall 10% reduction in NP accelerator utilization and a 5% overall reduction in research activities when compared to FY 1984 operating levels. LAMPF was more heavily impacted than the NP program norm because of relatively high escalation rates projected by LANL for FY 1985. LAMPF beam hours for research in FY 1985 were reduced from 3000 hours (IRB Request) to 2450 hours (Congressional Request). SLAC injector operations for basic nuclear research was reduced by 50%, from eight weeks (IRB Request) to four weeks (Congressional Request).

Plant and Capital Equipment

- A $500,000 reduction in Accelerator Improvements and Modifications required dropping of a subproject to upgrade the Brookhaven Double MP by addition of an electrostatic intershield to the second stage tandem. Because this work is important to the success of the BNL Transfer Line construction project, it was incorporated into the Transfer Line construction project.

- An increase of $7,000,000 was provided in the Congressional Request over the IRB Request for the BNL Transfer Line project (+$5,300,000 in Construction and +$1,700,000 in Capital Equipment).

- A $1,000,000 increase in General Plant Projects was part of a Departmental initiative to improve plant maintenance at the national laboratories.

- An $18,100,000 decrease ($1,100,000 in Capital Equipment; and $17,000,000 in Construction) in the Continuous Electron Beam Accelerator Facility (CEBAF) project reduced CEBAF activities in FY 1985 from a "fast-track" schedule envisioned in the IRB Request to architect-engineering work, detailed design beyond conceptual design, and preliminary site work.

- There was a $100,000 increase in capital equipment for detectors at Bevalac.

B. MANAGEMENT INITIATIVES

1. **According to the NP budget justification (Congressional Budget Request, FY 1985, Volume 4, p. 79), the FY 1985 NP budget request of $183,600,000 reflects $1,300,000 for savings resulting from management initiatives in the area of administrative processes/ field structure. What specific initiatives will result in these savings?**

   Answer: This management initiative is one of several initiatives which reflect the first implementation efforts of the DOE with regard to recommendations contained in various studies of departmental operations, including the President's Private Sector Survey on Cost Control (The Grace Commission) and the Federal Laboratory Panel of the White House Science Council (The Packard Report), as well as the Administration's program for improved management systems known as Reform 88.

   The $1,300,000 in the NP program represents savings in FY 1985 resulting from improved management of government owned, contractor operated (GOCO) facilities. This initiative involves improved utilization of private sector business practices by GOCO contractors through reduced procedural controls and heightened reliance on policy issuances and performance evaluation by the DOE Operations Offices. Cost initiatives for improved GOCO performance and reduction in reporting detail will lead to DOE management oversight at a higher level and to improved opportunities for innovation and implementation of new management processes by GOCO contractors. These savings will occur at all eight DOE operations offices and major contractors.

2. **Who will determine how these specific initiatives result in these savings?**

   Answer: These initiatives will involve a wide variety of activities including a thorough examination of reporting requirements and reductions in those requirements and a thorough examination of procedural requirements levied on our contractors in such areas of achievements of socioeconomic procurement goals, management of subcontractor activities, program and management planning activities and others. In each case the principal staff or program office responsible for the activity being examined will be required to identify savings opportunities and initiate the actions to implement those activities. For example: reduction in procurement reporting requirements would be directed by the Procurement Office, reduction in ADP reporting by the Office of ADP Management and so forth. The overall effort will be coordinated and results will be assessed by the Assistant Secretary for Management and Administration.

3. **How will these savings be apportioned among the DOE Operations Offices, laboratories, and other contractors?**

   Answer: All field offices and GOCO contractors will be expected to contribute efforts to achieve these savings. The impact on any individual organization will depend upon our assessment of the collective affect of eliminating or consolidating reporting requirements or simplifying procedures. For example: if a particular organization has estimated that meeting a particular reporting requirement requires four staff years of effort and that requirement is eliminated, we would expect the organization in question could reduce their overhead staffing by four staff years. While the data for making these estimates are not precise we believe it is sufficient to arrive at a reasonable basis to allocate the resultant savings without adverse impact on programmatic activities.

C. FACILITIES

1. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-ofhouse research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to each facility supported totally or partially by the Nuclear Physics program, including the following: (i) Argonne National Laboratory Argonne Tandem Linac Accelerator System (ATLAS) (ii) Brookhaven National Laboratory Double MP Tandem Facility, (iii) Duke University Triangle Universities Nuclear Laboratory (TUNL) Cyclograaf Accelerator, (iv) Lawrence Berkeley Laboratory (LBL) Bevalac Accelerator Complex, (v) LBL 88-Inch Cyclotron, (vi) Los Alamos National Laboratory Clinton P. Anderson Meson Physics Facility (LAMPF), (vii) Massachusetts Institute of Technology William H. Bates Linear Accelerator Center, (viii) Oak Ridge National Laboratory (ORNL) Holifield Heavy Ion Research Facility (HHIRF), (ix) Texas A&M University Cyclotron, (x) University of Washington Three-Stage Tandem Van de Graaf Accelerator Facility, and (xi) Yale University A. W. Wright Nuclear Structure Laboratory Model MP Tandem Van de Graaff Accelerator. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

   Answer: For the 11 facilities specifically cited, the requested information is provided in Sections C.1.0 through C.10.0. Facility-wide information on the Stanford Linear Accelerator Center (SLAC) is provided under High Energy Physics. Specific information on the new SLAC Injector is provided below:

   SLAC Injector for
   Basic Nuclear Research
   (B/A in thousands of dollars)

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Operating Expenses					
Medium Energy					
Operations	$ 0	$ 0	$ 0	$ 95	$ 1,090
In-house research	0	0	0	0	0
Construction					
Accel. Improv. & Mod.	0	0	0	1,650	0

   All of the above funds are from Nuclear Physics.

2. **How much funding has been provided by other agencies such as the National Science Foundation for each of the facilities enumerated in question 1 above?**

   Answer: For the 11 facilities specifically cited, the requested information is provided in Sections C.1.0 through C.10.0. There is no other agency support of the new SLAC Injector.

3. **What is the Nuclear Physics Program's user policy for each of the facilities listed in question 1 above?**

Answer: At each of the national facilities (ANL Tandem/Linac, BNL Double MP, LBL Bevalac, LBL 88-inch Cyclotron, LAMPF, MIT Bates, and ORNL Holifield) and the new SLAC Injector, beam time for nonproprietary work is available to all the Nation's scientists on the basis of scientific merit and technical feasibility of proposals reviewed by peer committees called program advisory committees. The program advisory committee for a given facility reports to the director of that facility.

To complement the seven national accelerator facilities, the Nuclear Physics program supports dedicated on-campus accelerators at Yale University, Duke University, the University of Washington, and Texas A&M University. While each of these on-campus facilities has an important visitor program, they are operated principally for the research use of the host university's faculty, postdocs, and graduate students.

Detailed statements of user policy are provided in Sections C.1.0 through C.10.0.

4. **For the period FY 1981 - FY 1985, by facility and by user, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?**

Answer: For the 11 facilities specifically cited, the requested information is provided in Sections C.1.0 through C.10.0. There is no reimbursable research at the new SLAC Injector.

1.0 Argonne National Laboratory (ANL)
Argonne Tandem Linac Accelerator System (ATLAS)

1. **What new science is being explored by this facility? What scientific opportunities are being exploited?**

Answer: The science of nuclear physics concerns itself with the properties of atomic nuclei and nuclear matter. The present prototype superconducting linac at Argonne, and especially the full ATLAS facility when it is completed in 1985, addresses important aspects of this field. By providing precision beams of heavy ions in the energy range comparable to the internal energies in nuclei, ATLAS can contribute in a unique way.

The properties of rapidly rotating nuclei are an important frontier area of experimental investigation. The characteristics of ATLAS are especially well suited to these studies. For studies of shape transitions, of possible super-deformed nuclei, and of the reordering of the protons and neutrons in nuclei under extremes of rotations, ATLAS will have capabilities unexcelled in the world. The fact that for several years the world's record in the highest measured discrete spin came from the prototype linac that is the first stage of ATLAS is an early indication of the capabilities of this technology. The insights and simplifications to be gained from the study of high spin nuclei is considerable and the research opportunities with ATLAS are at the forefront of this area.

ATLAS, as well as the present linac, represents a powerful facility to study the physics of interaction between colliding nuclei at energies comparable to nuclear binding energies. How do nuclei fuse? What are the systematics for fission? How are mass and energy exchanged by colliding nuclei? These are major areas of study for which the unique energy variability and timing of ATLAS beams make it into a very effective facility. The good energy resolution and easy energy variability also permit exploration of resonance studies--an important class of physics in this area.

An important dimension in nuclear structure is that represented by changes in the number of neutrons versus protons. In regions of a great excess of either neutrons or of protons, the question arises whether this imbalance affects the relative importance of the effective internucleon interactions. This would be reflected in changes in the masses of nuclei, in different shell closures, and thus in different shapes. ATLAS is uniquely suited to investigate such questions and to search for new nuclei because of the capability to easily provide the appropriate energy-projectile combination, which is of crucial importance in these studies with often extremely low production cross sections.

A nucleus is a quantal system, built from a number of strongly interacting particles, and reveals the coexistence and interplay of an astonishingly rich spectrum of motions, some involving one or a few nucleons or some involving the coherent motion of many nucleons. The behavior of these excitations, as a function of mass, proton-neutron ratio, angular momentum, and energy provides a controlled laboratory in which to test and develop models of nuclear structure. The heavy ion beams from ATLAS with precision properties can serve as valuable probes in delineating behaviors of collective excitations, giant resonances, cluster structures, and shape isomers.

Symmetry considerations in physics play a very fundamental role. The nuclear quantal system, despite its complexity, shows considerable order and displays fundamental symmetry properties. Studies with heavy ion beams from ATLAS can significantly contribute to the questions of symmetry effects on statistical properties in nuclei, as well as on those of individual levels. For instance, the study of hyperfine structure by high-resolution laser spectroscopy can yield key information on symmetry properties of certain nuclear states. And the discovery and study of relatively long-lived exotic configurations or "shape isomers" has the potential of opening entirely new perspectives on nuclear symmetries.

Nuclear processes and the properties of nuclear matter play a fundamental role in determining the basic structure and evolution of the universe. Accelerator-based nuclear physics can make essential contributions. Already with the prototype linac, important properties of heavy nuclei in the context of nuclear astrophysics have been measured by making use of the high sensitivity technique of accelerator mass spectrometry, with the necessary high energies and precision beam properties being provided by the existing linac. This technique will be expanded at ATLAS allowing, for example, for unique measurements in connection with the solar neutrino problem.

Accelerator-based atomic physics has opened new avenues for the study of highly ionized atoms. The precision beams from the linac will allow one to expand these measurements with unique capabilities to ions over a wide mass range.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

Answer: The Argonne superconducting linac, the first section of which started operation in 1978, was the first superconducting accelerator of any kind to be used for the acceleration of projectiles heavier than the electron. It was used as a research tool for four years before any other superconducting accelerator of ions was operational. When the ATLAS system is completed in 1985, the linac will have at least twice the accelerating power of any other superconducting heavy ion linac that is existing or planned. Thus, the Argonne linac is clearly playing a unique role in the development of a powerful new accelerator technology. Moreover, since the technology is based on the use of niobium, the best material for RF superconductivity by a big margin, the Argonne technology is likely to continue in its pioneering role for a number of years.

The present tandem-linac system and the coming ATLAS are specifically aimed at the needs of precision nuclear structure physics. Thus, the emphasis is on overall precision and versatility rather than on high beam energy. ATLAS should be viewed as being complementary to other accelerators such as the MSU cyclotron which will provide higher energy beams but is designed for entirely different kinds of nuclear research.

The ATLAS system has performance characteristics that are comparable with two other accelerators: (1) the UNILAC at Darmstadt, Germany and (2) the Oak Ridge Holifield Heavy Ion Research Facility, a very large tandem injecting into a cyclotron. The complete tandem-cyclotron system at Holifield provides a beam energy that is similar to ATLAS, but ATLAS remains far superior with respect to operational flexibility (e.g., energy variability).

The German UNILAC provides larger beam currents and can accelerate a wider range of projectiles, but with ATLAS energy changes are much easier to achieve.

Overall, the distinctive features of ATLAS are exceptional flexibility and beam quality, including characteristics such as rapid computer-controlled energy variability over the full energy range, good energy resolution, exceptionally short beam pulses, and an unusual degree of operational ruggedness.

3. **What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?**

Answer: The research instrumentation both at the present prototype linac and at the future ATLAS facility is tailored to the precision beam properties provided by the accelerator. Extensive use is made in time-of-flight measurements and other applications of the ultrashort pulsed-beam structure. High resolution spectrometers are employed in both target areas to make use of the good energy resolution.

Experimental devices presently available at the prototype linac include:

(1) A 65" diameter scattering chamber, with four independently movable detector rings and recent additions of a long flight path and an electrostatic deflection system;

(2) A high resolution, split-pole magnetic spectrograph with a sophisticated focal plane detector providing for position, differential energy-loss, total energy, and time-of-flight;

(3) A gamma ray facility with sum-spectrometer/multiplicity filter and accurate recoil-distance plunger;

(4) A thin-wall neutron time-of-flight chamber;

(5) An electron spectrometer, presently a normal conducting Gerholm-type spectrometer but soon to be replaced by an already assembled and tested superconducting-solenoid spectrometer;

(6) A cryogenic helium-jet/laser setup;

(7) A small, multipurpose scattering chamber; and

(8) A general purpose beam line.

For ATLAS, a substantial increase in our experimental capabilities is planned with the following devices:

(1) A multielement BGO gamma ray detector system to be constructed by a collaboration between the University of Notre Dame and ANL. This facility will ultimately consist of a BGO crystal array and Compton-suppressed germanium spectrometers arranged in two rings around the array;

(2) A scattering facility which will have provisions for mounting a number of large area position-sensitive gas detectors for singles and coincidence measurements, for mounting time-of-flight detector systems with flight paths in excess of several meters, for performing experiments in a clean, hydrocarbon-free vacuum, and for mounting experimental configurations with the possibility for out-of-plane measurements and independent motion for these detectors;

(3) A split-pole spectrograph, previously used at the Argonne tandem, will be moved to the new ATLAS experimental area. Due to its large dynamic range, it has several advantages for heavy ion reactions if compared to a larger "Q3D" spectrograph. Several charge states can be detected simultaneously and excitation energies from elastic to deep inelastic scattering are covered with one magnet setting;

(4) A project to satisfy the data acquisition requirements of ATLAS has been implemented. The system consists of three major hardware components and considerable software support. The hardware will consist of a CAMAC system, a multibus-based front-end processor utilizing parallel processing and a super-mini computer. It is anticipated that the software will be useful for analysis purposes by mid-1984 and the hardware front end will be ready for the first experiments on ATLAS.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer:

(1) Study of discrete high spin states. The physical picture emerging from the Argonne work illuminates the interplay of single-particle and collective nuclear excitation in nuclei at high angular momentum;

(2) Demonstration, for the first time, of the predicted oblate-prolate shape changes in rapidly rotating heavy nuclei;

(3) Observation of nuclear molecules formed between medium weight nuclei in some of the heaviest systems in which such effects have been seen. These are measurements of resonances in heavy ion collisions, with a detailed analysis of the structures observed;

(4) Observation of subbarrier enhancement and the systematic dependence on neutron number of fusion between heavy nuclei;

(5) Study of fusion-fission excitation functions in very heavy systems establishing large angular anisotropies and relatively long-lived, compact nuclear states in compound nuclei much heavier than any stable nucleus;

(6) Observation of superdeformed shapes in compound nuclei at high angular momentum and low excitation energy;

(7) Ultrasensitive detection of heavy radioisotopes resulting, for example, in the lifetime measurements of ^{32}Si and ^{60}Fe--both of considerable interest to geophysical and astrophysical research.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: The ATLAS accelerator is now under construction and will be completed in FY 1985. In the meantime, the present prototype linac is being used for research. The first sections of this linac were initially put into operation in 1978 and the final section was added in 1982.

The ATLAS construction project, which will double the accelerating power of the present linac and will add a large, new experimental area, was started in FY 1982 and will be completed in FY 1985. The new machine is scheduled to start accelerating ion beams in April 1985.

The experimental apparatus to be used with beams from ATLAS is being built with capital equipment funds that are allocated on an annual basis. The first allocation of this kind was in FY 1983. A rudimentary experimental system is expected to be in place when ATLAS first goes into operation in FY 1985.

The President's Budget for FY 1985 contains Accelerator Improvement funds with which to fabricate a testbed accelerator section. This section is the key element of a maintenance system that is designed to upgrade the performance of the whole linac.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer:

Budgets Associated with ATLAS
(B/A in thousands of dollars)

Source of Funding	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Accelerator Operations					
Heavy Ion NP	$ 1,275	$ 1,320	$ 1,302	$ 1,780	$ 1,855
Low Energy NP	283	315	307	350	365
TOTAL	$ 1,558	$ 1,635	$ 1,609	$ 2,130	$ 2,220
Research					
Heavy Ion NP	$ 1,200	$ 1,700	$ 1,800	$ 2,300	$ 2,400
Low Energy NP	500	1,000	1,200	1,400	1,600
TOTAL	$ 1,700	$ 2,700	$ 3,000	$ 3,700	$ 4,000
Equipment					
Nuclear Physics	$ 500	$ 800	$ 1,300	$ 1,400	$ 1,600
GPP					
Nuclear Energy (81-84)	$ 300	$ 400	$ 100	$ 0	$ 0
BES (85)	$ 0	$ 0	$ 0	$ 0	$ 300
Construction	$ 0	$ 4,000	$ 3,700	$ 0	$ 0
Accelerator Improvement					
Nuclear Physics	$ 0	$ 0	$ 0	$ 0	$ 660
Basic Energy Sciences	$ 0	$ 0	$ 0	$ 0	$ 200

The amounts shown over the years FY 1981-FY 1983 show the increasing operation of the prototype superconducting linac accelerator; the increase shows the reallocation of research and operation funds from the tandem and other activities.

Budgets for research carried out at out-of-house facilities are not maintained separately. They are estimated to be between 5% and 10% of these operating budgets. Some BES-supported atomic physics research, amounting to less than $100,000 per year, is being carried out now. After FY 1985, this work is expected to increase.

7. How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: None.

8. For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.

Answer:

Staffing Associated with ATLAS

Fiscal Year	Man Years[a,b]
1981	33
1982	42
1983	47
1984	56
1985	55

[a] All manpower, including administrative and secretarial services.

[b] The amounts shown over the years 1981-1983 show the increasing operation of the prototype superconducting linac accelerator; the increase shows reallocation of research and operation effort from the tandem accelerator as well as other activities.

9. What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?

Answer: For the period FY 1981 - FY 1985, actual utilization of the Argonne Tandem Linac System (ATLAS) is given in the following table.

TANDEM/LINAC FACILITY UTILIZATION

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Beam Hours for Research	2964	3077	3279	4400	3050

For the ATLAS we estimate full utilization to be 6000 beam hours for research per year.

10. For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?

Answer: Most experiments with the Argonne linac facilities are carried out within one fiscal year, with a typical experiment requiring between two and three experimental runs of a few (typically three to five) days each. The best measure of completed experiments is the number of papers published and the number of reports at meetings (abstracts). These are also given year by year.

Experiments with ATLAS

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Experiments Carried Out	16	22	27	36	15
Experiments Completed (Publications)					
Papers	6	11	15	17	
Abstracts	18	17	16	22	

The experiments listed here are those done with the prototype superconducting linac accelerator for the period FY 1981-FY 1984.

11. What is this facility's user policy?

Answer: The Argonne linac facility is open to any prospective user. Persons interested in obtaining beam time must submit a written proposal which will be reviewed by a Program Advisory Committee (PAC). The recommendations of the PAC are the primary basis for the allocation of beam time.

The facility provides heavy ion beams, many major pieces of experimental apparatus, and the available electronics and computer facilities for data taking. Technical manpower and assistance are provided to the extent feasible.

To accommodate users of the facility, a designated outside-user liaison person has the responsibility for providing information and coordinating the available facility resources. An ATLAS users' handbook has been generated to provide information regarding the capabilities of the facility and the procedures for obtaining beam time and performing an experiment. Office space and some secretarial services are made available to users during their stay. Technical manpower and assistance is provided to the maximum extent possible.

A newsletter is sent out four times a year to keep users informed on the status and plans for the accelerator facility and on the physics being pursued. Two workshops to discuss the plans for the experimental area associated with ATLAS have been organized in the last two years. These have been well attended and have provided useful input which has been used in formulating plans. These workshops together with the PAC have so far provided outside advice which normally might have been obtained from a formal users organization. The formation of a users organization is planned for the near future.

12. For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?

Answer: None.

13. What is the mechanism by which specific research proposals for experiments at the facility are considered?

Answer: A Program Advisory Committee (PAC) exists which makes recommendations for priorities in the allocation of research time based on written proposals. Calls for proposals are currently issued three times a year. The PAC considers the written proposals and makes its recommendations. Decisions on beam time allocations are made by the Scientific Director of the facility with the recommendations of the PAC being the primary source of input. At present, with only the prototype linac operational, approximately two thirds of the available beam is designated for experiments with the remaining one third allocated for beam and instrumentation development. The PAC consists of six voting members and two nonvoting members. The voting members are appointed for two year terms with staggered appointments to assume a rotating membership.

14. How many research proposals have been submitted over the past five years, and how many of these have been approved?

Answer: In the 4-year year period from FY 1980 to FY 1983, outside-user usage of accelerator beam time increased from 30% (FY 1980) to about 50% (FY 1983). An average of about 50 experimental runs per year were carried out during this period. The outside users came from universities, other DOE national laboratories, and other institutes, both domestic and foreign.

Since October 1983, 34 proposals for experiments requesting 165 days of beam time have been submitted of which 24 were approved and allocated 93 days of beam time (56% of the requested time). During this same period, 14 proposals for development time were submitted, requesting 36 days, of which 10 were approved and allocated 22 days of beam time (60% of the requested time). Approximately 50% of the experiments performed involved ANL/outside-user collaborations and in 30% of the experiments, an outside user was spokesman.

15. How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?

Answer: The total number of university personnel (faculty and graduate students) who participated in research at the tandem or the prototype superconducting linac system over this period was 110. The number participating during specific years is shown below:

Fiscal Year	University Users
1979	14
1980	29
1981	45
1982	31
1983	56

In FY 1979, all experiments were performed on the tandem. In FY 1980, 10 university users used the tandem, while 19 worked on experiments using beams from the prototype linac. In more recent years, essentially all the university users have used beams from the linac. Our outside users records do not identify faculty or graduate student status. However, in general, approximately one third of university users are faculty, and two thirds are either graduate students or postdoctoral research associates.

16. **How many industrial researchers have utilized the facility over the past five years?**

Answer: None.

17. **How many researchers from foreign institutions have utilized the facility over the past five years?**

Answer: The total number of experimenters from non-U.S. laboratories over the five year period is 40 from 18 institutions and universities. The breakdown by year is shown below:

Fiscal Year	Foreign Users
1979	7
1980	6
1981	9
1982	16
1983	13

In FY 1980, the foreign users used beams from the tandem. In all other years, the users participated in experiments utilizing beams from the prototype linac.

18. **How many researchers from other agencies have utilized the facility over the past five years?**

Answer: None.

19. **What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?**

Answer: There are many potential future development possibilities for this accelerator facility, but there are currently no approved plans to undertake any of them beyond the activities identified in the FY 1985 budget request. New research instruments and experimental devices will be developed as the physics research program progresses. We intend to give high priority to the exploitation of the facility's unique capabilities.

20. **Please provide a copy of the facility's latest annual report.**

Answer: Attached is a copy of Argonne National Laboratory's "Physics Division Annual Review, 1 April 1982-31 March 1983." **(Note: Excerpts from this report follow.)**

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ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PHYSICS DIVISION ANNUAL REVIEW
1 APRIL 1982—31 MARCH 1983

Donald S. Gemmell
Division Director

June 1983

Preceding Annual Reviews

ANL-80-94	1979—1980
ANL-81-79	1980—1981
ANL-82-74	1981—1982

NUCLEAR PHYSICS RESEARCH

Introduction

The research program in nuclear physics in the Physics Division spans a broad range of activities and contributes to many of the major questions in the discipline. Activities may be roughly divided into three broad categories. Research with the tandem-linac in heavy-ion physics is doing well, though laboring under severe budgetary constraints, and outside use of the facility has increased substantially. Progress on the construction of the full ATLAS facility is coming along expeditiously and it is expected to be completed on schedule in 1985. In medium-energy physics, activities are continuing at LAMPF, as well as other accelerators, though considerable effort was devoted this year to the preparation of a proposal for a national electron accelerator facility. The medium-energy experiments are concentrated (a) on understanding pion propagation and absorption in nuclei, (b) studies of weak interactions and particularly a neutrino-oscillation experiment at LAMPF, (c) studies of the two-nucleon system, and (d) some nuclear-structure experiments. The third major area of activity is in nuclear theory where the role of sub-nucleonic degrees of freedom in the nucleon-nucleon force and in nuclear matter are explored and studies of the shell-model theory of nuclear structure are carried out, as well as work on reaction theory in both the heavy-ion and the intermediate-energy regime.

Some of the highlights of the past year are in the continued improved operation of the superconducting linac, where outside user participation has almost doubled to near 50% of the research.

The construction of ATLAS is proceeding well and there is every reason to expect that it will come into operation on schedule.

Evidence has been found from gamma-ray studies for prolate-to-oblate shape changes in Dy isotopes.

Studies of fusion cross sections over a range of Ni + Sn isotopes have revealed a striking change (~ order of magnitude) over the 20% range in neutron excess.

In medium-energy physics a survey of inclusive charge-exchange $(\pi^{\pm},\pi^{0})$ reactions has been carried out over a variety of targets, showing great sensitivity to the neutron excess. This complements the study of inclusive pion inelastic scattering experiments done previously--experiments which were fully analyzed and published during the past year.

The importance of pion exchange currents in axial vector beta decay has been conclusively demonstrated through studies of the ^{16}N beta decay.

A substantial proposal was prepared for a 4-GeV electron microtron, GEM, which would serve as a major national center for the study of electromagnetic interactions in nuclear physics.

The role of the first non-nucleonic degree of freedom, the Δ, in the nucleon-nucleon force, in the wave function of the three-nucleon system, and in nuclear matter has been explored through theoretical calculations.

A precision measurement was carried out of the branching ratio in the decay of ^{7}Be which refuted a recent experiment that could have led to substantive changes in astrophysical calculations and had a direct bearing on the solar neutrino problem.

II. RESEARCH AT THE TANDEM AND SUPERCONDUCTING LINAC ACCELERATOR

Introduction

The completion of the superconducting linac booster has made it possible to perform experiments on a more-or-less regular basis, with occasional accelerator shutdown to allow for maintenance and ATLAS building construction. The development of an improved ion source has made feasible experiments with "difficult" beams such as Ca and Ti. The experimental facilities are also nearly complete. All these factors have benefitted and strengthened the heavy-ion research program. The overall thrust of this program continues to be the systematic study of nuclear structure at high spin, high excitation energy, and nuclei far from stability; and the distribution of reaction strengths with increasing beam energy and the influence of nuclear structure on the reaction mechanism. Several new directions have been developed including investigations of the relaxation process following fusion, momentum transfer of evaporation residues, fusion forming very heavy compound systems and shape changes in heavy transitional nuclei.

Significant information and understanding of shape transitions in nuclei have been obtained from experiments on soft transitional nuclei. Striking prolate-to-oblate changes have been observed in ^{153,154}Dy, while decoupled $i_{13/2}$ neutron bands with both prolate and oblate shapes have been identified in ^{186}Hg. These studies have led to a good description of the nuclear shape as a function of spin and neutron number and to a better appreciation of the shape-driving force provided by decoupled high-j quasiparticles. Measurements of lifetimes of continuum states and feeding times of high-spin yrast states indicate the coexistence of both collective and single-particle structures above the yrast line in transitional nuclei. In the program on proton $(h_{11/2})^n$ valence structures outside a N = 82, Z = 64 core, a long-lived (40-μs) isomer was discovered in $^{152}_{70}$Yb$_{82}$, extending the body of data which is very well predicted by shell-model calculations.

Cross-section measurements of evaporation residues formed in bombardment of Sn isotopes with ^{58}Ni and ^{64}Ni have revealed interesting cross-section differences as a function of the neutron number of the compound nucleus. Experiments are underway to determine whether this neutron-number dependence is due to differences in compound nucleus formation or differences in fission competition. Residues with low production cross section have been detected through delayed α activity. The aim of these programs is to elucidate the influence of shell structure in fusion, the dynamics of the fusion process, and the survival probability of heavy residues--of relevance for the production of superheavy nuclei. The earliest stages following fusion have been probed by measurements of neutron spectra and neutron multiplicity distributions. Suppression of neutron emission is observed and may be related to trapping in a superdeformed potential well as the initially highly deformed state relaxes.

While it is well known that the evaporation residue cross section ceases to increase beyond a certain center-of-mass energy, the exact cause for this phenomenon has not been unambiguously identified. The onset and growth of incomplete fusion, quasifission, deep-inelastic scattering and fragmentation are responsible, but the distribution of reaction strength with beam energy has yet to be definitively ascertained. To determine this distribution systematic studies will be necessary. The experiments at Argonne focus on measurements of discrete states and of the velocities of evaporation residues. In a study of the $^{37}Cl + ^{208}Pb$ reaction, which is of the first type, it has been observed that neutron and proton pick-up channels dominate the transfer and deep-inelastic reactions, respectively. A broad set of singles and coincidence experiments is based on measurements of residue velocities, which allow a decomposition of the cross sections associated with full and partial momentum transfer. Interesting differences in the cross section for complete momentum transfer have been observed in producing the same compound nucleus with different entrance channels.

The accelerator mass spectrometry (AMS) program continues both at the tandem and at the linac. AMS has been demonstrated to be an extremely effective tool for measuring very low-level concentrations (10^{-10} to 10^{-15}) of radioisotopes. The Argonne program concentrates on nuclear-physics-related problems and includes the determination of the half-lives of ^{44}Ti (completed) and ^{60}Fe (in progress), a search for doubly-charged negative ions and development of methods for detecting low concentrations ($\sim 10^{-15}$) of ^{41}Ca, which may have applications for dating in geology and archeology.

The experimental facilities associated with the linac are close to completion. Currently being installed are a general-purpose beam line, a beam line for the Purdue superconducting-solenoid electron spectrometer, and diagnostics and protection for the beam-line vacuum system. Improvements and upgrade of present equipment continue. A position-sensitive ionization detector has been installed in the spectrograph with good mass, charge, energy, and position resolution, while a large-area ΔE-E detector and channel-plate detectors have been built for evaporation residue measurements. A new sophisticated plunger for recoil-distance lifetime measurements has been extensively tested and used in several experiments. The ANL-Iowa-Minnesota apparatus for optical-hyperfine-interaction measurements is close to completion. Finally, substantial effort has been devoted by the research and technical staff towards plans and designs for beam-line layout, experimental equipment, and data acquisition at ATLAS. The preparation and construction of the ATLAS experimental areas will consume an increasing fraction of our total effort in 1983-1985.

A. HIGH ANGULAR MOMENTUM STATES IN NUCLEI

Our studies have concentrated on and documented several cases of shape changes which occur at high spin. We have devoted a fair fraction of our effort on transitional nuclei (Dy and Er isotopes with N ~ 88 and ^{186}Hg) since these are soft with respect to the shape degree of freedom and thus most susceptible to shape changes. We are also interested in the nature of yrast states at very high spin and have identified states in ^{147}Gd with spins in excess of 81/2, the highest recorded spin for an yrast state. Here the level structure and feeding times suggest the persistence of an oblate coupling scheme up to and slightly above this spin. Efforts to investigate the structure of continuum states above the yrast line involve measurements of lifetimes of these states, either directly or indirectly through the feeding times of yrast states. In the program studying the $(\pi h_{11/2})^n$ configuration outside Z = 64 and N = 82, a long-lived 10^+ isomer (with half-life corresponding to ~0.01 Weisskopf unit) was discovered in $^{152}_{70}\mathrm{Yb}_{82}$, a nucleus very near the proton drip line. This confirms theoretical expectations for the forbidden E2 decay in the half-filled shell (n = 6); in fact, our data on the $(\pi h_{11/2})^n$ couplings with n = 3-6 show remarkably good agreement with shell-model calculations.

An active collaboration continues with Prof. P. J. Daly's group from Purdue University. Several projects are also joint ventures with overseas scientists from Copenhagen, GSI, Jyväskylä, Orsay, and Strasbourg.

a. Gamma-Spectroscopy at Very High Spins in ^{147}Gd (S. Bjornholm,* J. Borggreen,* J. Pedersen,* G. Sletten,* P. Chowdhury, H. Emling, D. Frekers, R. V. F. Janssens, T. L. Khoo, Y. H. Chung,† and M. Kortelahti†)

One of the striking results of the yrast population experiment (see section A.g.) was the observation that the yrast states in ^{147}Gd were strongly populated (>80% of ground state strength) even at spin 65/2.

Gamma-gamma coincidence measurements have been performed for transitions reaching ~8 MeV above the 550-ns isomer at excitation 8.590 MeV and spin $49/2^+$. In another experiment angular distributions were measured and the analyses established spins along the yrast line up to 79/2 and E ~ 17 MeV (Fig II-1); these are the highest values of both spin and excitation energy observed from yrast states in heavy nuclei. In all experiments an array of 14 NaI detectors was used to select high multiplicity events which feed the 550-ns isomer. Consequently, only γ rays feeding the isomer were accepted, resulting in very clean spectra.

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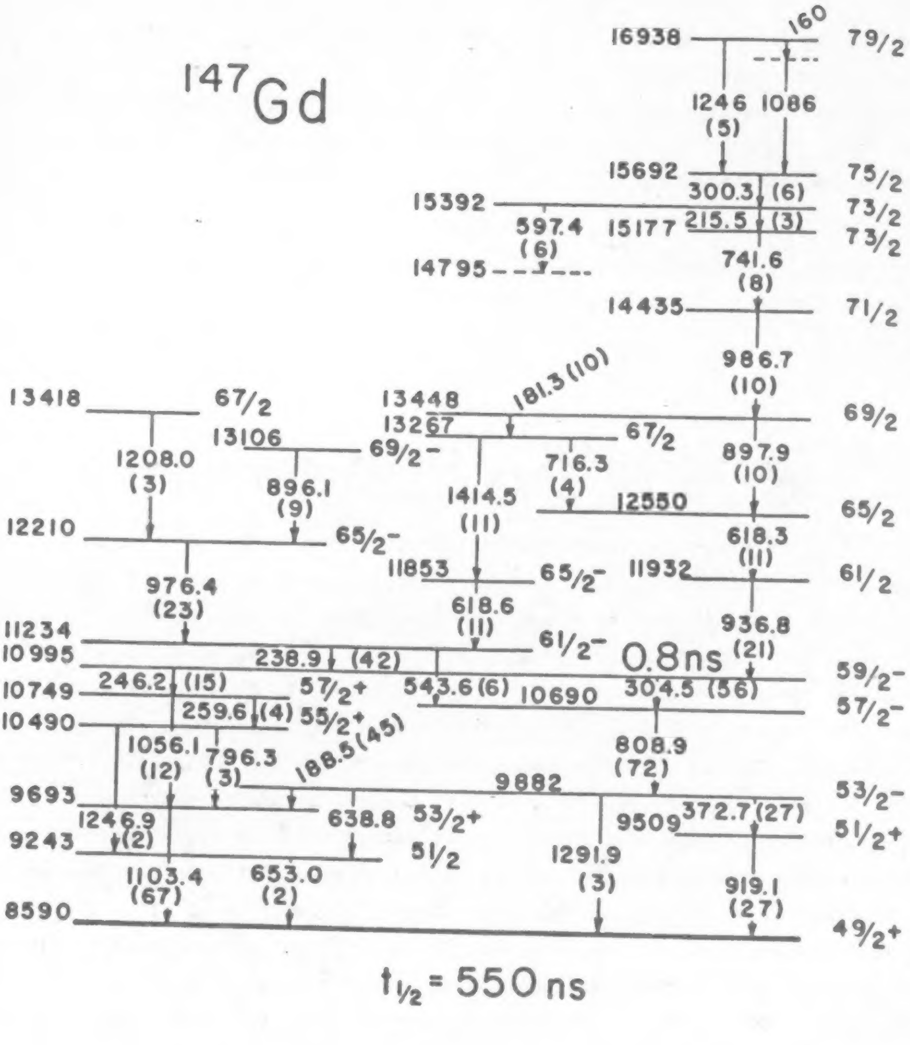
¹⁴⁷Gd
16938
160
79/2
1246
(5)
1086
15692
75/2
300.3
(6)
15392
73/2
597.4
(6)
15177
215.5
(3)
73/2
14795
741.6
(8)
14435
71/2
181.3 (10)
986.7
(10)
13418
67/2
13448
69/2
13267
67/2
13106
69/2−
1208.0
(3)
896.1
(9)
1414.5
(11)
716.3
(4)
897.9
(10)
12550
65/2
12210
65/2−
11853
65/2−
618.3
(11)
11932
61/2
976.4
(23)
618.6
(11)
936.8
(21)
11234
61/2−
0.8ns
10995
238.9
(42)
59/2−
10749
246.2
(15)
57/2+
543.6 (6)
10690
304.5 (56)
57/2−
10490
259.6
(4)
55/2+
188.5 (45)
1056.1
(12)
796.3
(3)
808.9
(72)
9693
9882
53/2−
1246.9
(2)
638.8
53/2+
9509
372.7 (27)
51/2+
9243
51/2
1291.9
(3)
1103.4
(67)
653.0
(2)
919.1
(27)
8590
49/2+
$t_{1/2}$ = 550 ns

Fig. II-1. Level Scheme of ^{147}Gd on top of the $49/2^+$ isomer located at 8.59 MeV. Spins and parities have been deduced from angular distribution measurements.

Independent-particle model calculations come out with configuration assignments in reasonable agreement with the spins and energies measured, but they also tell us that within a few more units of angular momentum the nucleus has to find extraordinary ways of producing the spin, either by exciting nucleons from the next major shell or from collective rotation.

One way to distinguish between these two modes may be a determination of subnanosecond lifetimes and feeding times of the upper states; for this reason Doppler shift measurements with a plunger are planned.

b. Shape Change in ^{153}Dy (M. Kortelahti,* Y. H. Chung,* P. J. Daly,* Z. W. Grabowski,* A. Pakkanen,* P. Chowdhury, R. V. F. Janssens, and T. L. Khoo)

The yrast configurations of nuclei with $N \geqslant 90$ originate from the collective rotation of prolate shapes, while those of nuclei with $N \leqslant 86$ arise from the alignment of a few high-j orbitals, leading to oblate shapes. Our studies of the transitional nucleus $^{154}_{66}\mathrm{Dy}_{88}$ have shown the first instance of a transition from prolate to oblate shapes with increasing spin ($I > 32$). $^{153}_{66}\mathrm{Dy}_{87}$ should also exhibit a similar shape transition. Indeed γ-spectroscopic studies through the ^{124}Sn (^{34}S,5n) reaction bear out this expectation, with the oblate shapes emerging for $I >$ 41/2. The occurrence of a 2.3-ns isomer with $I \sim 47/2$ provides strong evidence for this statement. The study of ^{153}Dy completes our systematic investigation of Dy isotopes with N = 82--88, allowing us to trace the evolution of nuclear shapes as a function of spin and neutron number. In the process we have observed the important role played by rotational alignment - induced by the Coriolis force - in shape transitions.

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c. Lifetime Measurements in ^{154}Dy (H. Emling,* P. Chowdhury, D. Frekers, R. V. F. Janssens, T. L. Khoo, W. Kühn, A. Pakkanen* Y. H. Chung,* P. J. Daly,* Z. W. Grabowski,* and M. Kortelahti,*)

We have recently published in Physical Review Letters the results of extensive γ-ray spectroscopic studies in $^{154}_{66}$Dy$_{88}$, which included lifetime measurements. Levels up to spin 34 or 35 were established, and at spin 33 a transition from collective to aligned-particle structure was observed in a heavy nucleus for the first time. The lifetimes suggest that this transition evolves through a series of triaxial shapes.

The earlier recoil distance lifetime measurements in ^{154}Dy had yielded results with large uncertainties for the yrast states in the spin region between 10 and 20, owing to the strong influence of slow (10-25 ps) side-feeding and the fact that the emphasis had been on short lifetimes (<10 ps).

We have performed new lifetime measurements in ^{154}Dy, focussing on the medium-spin states. A (^{34}S,4n) reaction was used to populate ^{154}Dy at a lower excitation energy and spin, to enhance the prompt feeding into the medium-spin range. Recoil-distance techniques were employed with a newly constructed plunger which fits inside the sum spectrometer. The use of the sum spectrometer made it possible to obtain very clean spectra for the ^{154}Dy channel of interest. (A method for isolating a single reaction channel has been found.)

The results, however, did not significantly improve the accuracy of the extracted lifetimes, because the feeding times from the non-yrast continuum states were slow, thereby reducing the sensitivity for measuring short lifetimes. On the other hand, the observation of this slow component suggests that the γ-deexcitation pathway goes through single-particle configurations, before finally feeding into medium-spin yrast states which, in contrast, are of collective nature. The single-particle configurations lie above the yrast line and are probably related to the aligned-particle structures which become yrast around spin 32. Analysis to extract the spin dependence of the feeding times is currently underway. When completed we should have important information for a detailed understanding of the structure of the continuum states which lie above the yrast line. We plan to identify the high-spin yrast structure of ^{155}Ho and to measure lifetimes here. The coupling of an additional proton to a soft ^{154}Dy could lead to interesting shape changes.

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d. Shape Changes at High Spin in ^{155}Er (G. Bastin,† F. Beck,* C. Schück,† D. Frekers, R. V. F. Janssens, T. L. Khoo, W. Kühn, and M. Kortelahti‡)

The occurrence of a shape change at high spin has been demonstrated in this laboratory for ^{153,154}Dy. While up to spin 41/2 and 32^+, these nuclei exhibit band structures similar to those observed in the deformed nuclei, at higher spins the level structure becomes rather irregular and resembles the one seen in spherical or slightly oblate nuclei. We made the suggestion that this change is due to the polarization of the core by the alignment under rotation of nucleons located in high-j orbitals. In order to test this hypothesis, studies of level structures in neighboring transitional nuclei are necessary. ^{155}Er was studied with the ^{125}Te(^{34}S,4n) reaction at 160 MeV and γ-γ coincidences, angular distributions and an excitation function were measured. The analysis is in progress.

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‡Purdue University, W. Lafayette, Indiana.

e. Lifetime Measurements of Continuum States in $^{154,152}Er$

(P. Chowdhury, I. Ahmad,* R. V. F. Janssens, T. L. Khoo,
W. Kühn, G. Rosner, Y. H. Chung,† P. J. Daly,† S R. Faber,†
Z. W. Grabowski,† M. Kortelahti,† J McNeill,† A. Pakkanen,†
H. Emling,‡ and D. Ward§)

Earlier measurements of the population patterns of the yrast states in $^{152}_{66}Dy_{86}$, together with multiplicity and angular distribution measurements of continuum γ rays, had yielded evidence suggesting the presence of collective structures built on high-spin aligned-particle yrast states in $^{152}_{66}Dy_{86}$. Direct information on the degree of collectivity can be obtained from the lifetimes of the continuum states.

We have employed a Doppler-shift attenuation method to measure continuum lifetimes in the $^{154}_{68}Er_{86}$ and $^{152}_{68}Er_{84}$ nuclei, using (^{64}Ni,4n) reactions. Continuum spectra were compared for the case where the residues were allowed to recoil into vacuum ($v_{recoil} \sim 0.04$ c), and stopped in a Au backing (~1.5 ps stopping times). Two 25 x 30 cm NaI crystals were gain-stabilized and used with 10-cm diameter central Pb collimators, in conjunction with a sum spectrometer and a Ge(Li) detector.

The use of Au stopping foils has eliminated severe normalization problems previously encountered with Pb stopping foils, which tend to be easily contaminated with light element impurities. The recent data are currently being analyzed. A preliminary analysis of the ^{154}Er data suggests lifetimes consistent with a high degree of collectivity in the continuum cascades. The lifetimes of statistical γ rays with 2 MeV $< E_\gamma <$ 4 MeV are also of interest, in light of recent results which suggest long decay times (~2 ps) for these γ rays in ^{152}Er. A more complete analysis is necessary to extract the lifetimes of the statistical transitions.

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‡GSI, Darmstadt, W. Germany.

§Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada.

f. Measurement of Feeding Times in ^{152}Dy (H. Emling, P. Chowdhury, Y. H. Chung,* P. J. Daly,* D. Frekers, Z. W. Grabowski,* R. V. F. Janssens, T. L. Khoo, M. Kortelahti,W Kühn, and A. Pakkanen*)

The structure of states above the yrast line can be directly probed by a measurement of the feeding times of the yrast states. To that effect, we have made recoil-distance measurements of feeding times for yrast states in ^{152}Dy with a (^{34}S,4n) reaction, using a newly constructed plunger which fits inside the sum spectrometer. This allows a study of the feeding times as a function of sum energy, and hence as a function of initial angular momentum. Analysis of the data is in progress.

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g. Yrast Population Patterns in a Wide Range of Nuclei (J. Borggreen,* G. Sletten,* R. V. F. Janssens, P. Chowdhury, T. L. Khoo, Y. H. Chung,† P. J. Daly,† Z. Grabowski,† and M. Kortelahti†)

The purpose of this experiment is to investigate the dependence on nuclear structure of the relative population of states on the yrast line. We have studied the population-pattern as a function of spin in the nuclei $^{148--156}$Dy, $^{154--160}$Er, ^{146,147}Gd. The nuclei were populated in ^{34}S- and ^{30}Si-induced reactions at beam energies chosen such that all compound nuclei were obtained with similar angular momenta and excitation energies. The analysis of the data has been completed. Striking differences have been observed between the feeding patterns in the light and heavy isotopes, in particular for the Dy isotopes. Indeed, ~100% of the γ-ray flux is measured along the yrast line up to the state having a spin corresponding to the largest value that can be obtained from the alignment of the valence nucleons on the symmetry axis (^{146}Gd being regarded as a core). This was observed for the nuclei ^{148,150,151,152}Dy which are known to have a slight oblate deformation. In contrast, in the well-deformed prolate ^{154,155,156}Dy nuclei, the intensity along the yrast line drops gradually starting from the lowest spin states. These findings are correlated with the nuclear structure, the level density in the vicinity of the yrast line and with the γ decay properties of the states populated. Calculations are currently underway by S. Åberg (Nordita). Preliminary results indicate that the main experimental trends can be accounted for with level densities obtained from the deformed independent-particle model.

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h. The $(\pi h_{11/2})^6$ Spectrum in $^{152}_{70}Yb_{82}$ (Y. H. Chung,* P. J. Daly,* Z. W. Grabowski,* M. Kortelahti,* J. McNeill,* P. Chowdhury, R. V. F. Janssens, T. L. Khoo, R. D. Lawson, and H. Emling)

In continuation of our systematic study of N = 82 nuclei above the N = 82 and Z = 64 doubly closed shells, we have investigated the nucleus $^{152}_{70}Yb_{82}$. Shell-model calculations, using $^{146}_{64}Gd_{82}$ as a closed core, have been extremely successful in describing the $(\pi h_{11/2})^6$ level structure in the 3, 4 and 5 proton nuclei $^{149}_{67}Ho$, $^{150}_{68}Er$ and $^{151}_{69}Tm$, respectively.

A $^{96}Ru(^{58}Ni,2p)^{152}Yb$ reaction was employed in conjunction with a newly installed beam deflector system, which was used to pulse the beam. A 40/s 10^+ isomer was found. Both the halflife (~0.01 Weisskopf unit) of the 10^+ state and the transitions below the 10^+ isomer are in excellent agreement with theory. The $10^+ \rightarrow 8^+$ decay is forbidden in the half-filled $\pi h_{11/2}$ proton shell and hence is expected to have a long lifetime for E2 decay. An alternative decay of the 10^+ involves a $10^+ \rightarrow 7^-$ E3 transition. The experimentally observed decay of the 10^+ is seen to proceed strongly through the 7^-, 5^-, and 3^- states to the 0^+ state, as expected from the theoretical calculations.

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i. Spectroscopy of ^{100}Cd (L. Clemann,* M. Barclay,* D. Cacic,* W. C. Ma,* C. Maguire,* J. Hamilton,* D. Frekers, R. V. F. Janssens, and T. L. Khoo,

By taking advantage of the fact that heavy-ion reactions can be used to produce nuclei far from stability, the reaction ^{46}Ti(^{58}Ni,2p2n) has been used to study the spectrum of the very neutron-deficient nucleus ^{100}Cd. ^{100}Cd in its ground state has a $g_{7/2}$ neutron pair and a proton hole outside the N = 50 closed shell and it is expected that these configurations will have a considerable influence on the yrast spectrum. The spectroscopy of Cd isotopes with larger neutron number is reasonably well known, and information on ^{100}Cd will make it possible to trace the evolution of different shapes as the neutron number increases from the closed shell N = 50. In the experiment we used the technique of $\gamma - \gamma$ coincidences in conjunction with the sum spectrometer to identify transitions in ^{100}Cd. The analysis of the data is in progress.

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j. Prolate and Oblate Rotational Bands in ^{186}Hg (R. V. F. Janssens, D. Frekers, P. Chowdhury, H. Emling, T. L. Khoo, W. Kühn, Y. H. Chung,* P. J. Daly,* Z. Grabowski,* and M. Kortelahti*)

The light Hg isotopes are located in a transitional region between spherical or slightly oblate nuclei and the well-deformed prolate rare earth nuclei. Evidence for shape coexistence has been reported for the light even-even Hg isotopes (i.e., A = 188--184). These nuclei have a small oblate ground-state deformation as well as a prolate minimum located slightly higher in energy (~500 keV). The present study aims at investigating the properties of the bands located in both minima. ^{186}Hg was extensively studied this year with the ^{156}Gd (^{34}S,4n) reaction at 165 MeV though γ-γ coincidence, angular distribution and excitation function measurements. A level scheme (Fig. II-2) has been deduced which shows the following main features: (i) the ground band is seen up to 6^+ and probably 8^+, (ii) the rotational band built on the prolate deformation is

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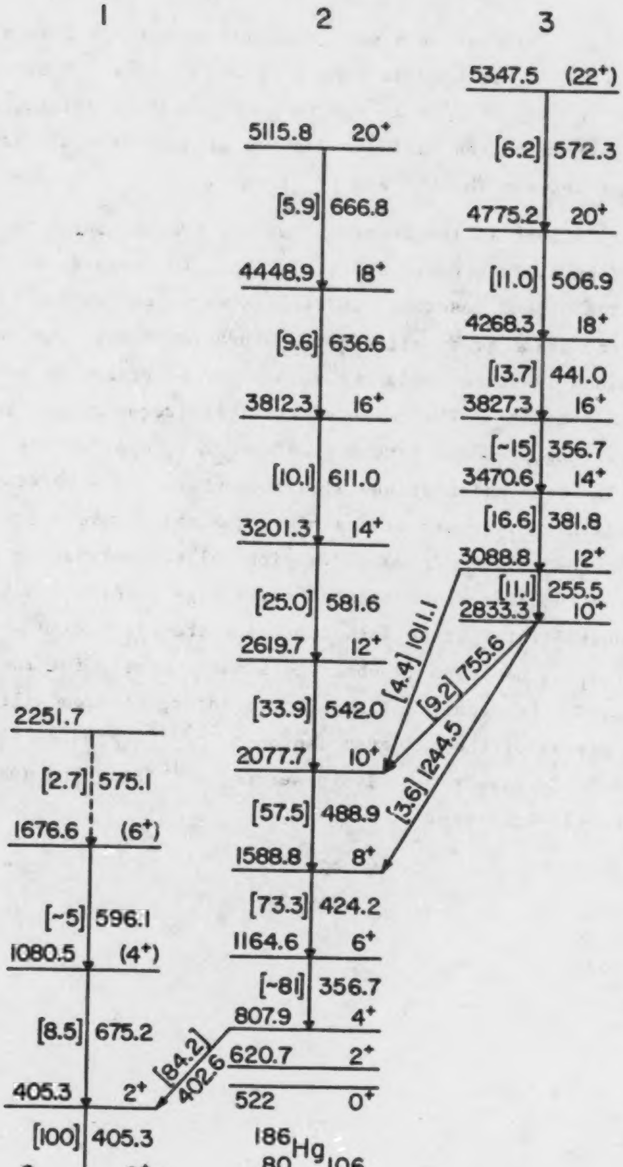
1
2
3
5347.5 (22+)
[6.2] 572.3
4775.2 20+
[11.0] 506.9
4268.3 18+
[13.7] 441.0
3827.3 16+
[~15] 356.7
3470.6 14+
[16.6] 381.8
3088.8 12+
[11.1] 255.5
2833.3 10+
5115.8 20+
[5.9] 666.8
4448.9 18+
[9.6] 636.6
3812.3 16+
[10.1] 611.0
3201.3 14+
[25.0] 581.6
2619.7 12+
[33.9] 542.0
2077.7 10+
[57.5] 488.9
1588.8 8+
[73.3] 424.2
1164.6 6+
[~81] 356.7
807.9 4+
620.7 2+
522 0+
[4.4] 1011.1
[9.2] 755.6
[3.6] 1244.5
2251.7
[2.7] 575.1
1676.6 (6+)
[~5] 596.1
1080.5 (4+)
[8.5] 675.2
405.3 2+
[84.2] 402.6
[100] 405.3
0 0+
186 80 Hg 106

Fig. II-2. Level scheme of ^{186}Hg.

identified up to 20^+ and shows a gentle upbending between levels with spin 14^+ and 18^+, (iii) a new band is seen from 10^+ to 22^+. It crosses the band discussed in (ii) at $I^\pi = 16^+$ without any apparent interaction. This band feeds the prolate band at 10^+ and shows also an irregularity in the energy spacings between the 12^+ and 14^+ levels.

Calculations in the framework of the Cranked Shell Model have been performed by S. Frauendorf and Z. Y. Zhang (University of Tennessee). The upbend described in (ii) is explained by the crossing of the prolate groundband by an aligned $i_{13/2}$ neutron band. The interaction between the bands is strong and, hence, only an upbending is predicted, in agreement with the data. The computed critical frequency and the gain in alignment resulting from the interaction are in good agreement with the experiment. The same calculations also account for the behavior of the new band. Here again $i_{13/2}$ neutrons are playing a major role but the motion takes place in the oblate minimum. In particular, the absence of interaction and the difference between the energy spacings in the two bands are well accounted for. These data represent the first case where the decoupling of $i_{13/2}$ neutrons is observed simultaneously for two different deformations. Further confirmation of this interpretation will be provided by an investigation of the odd-even isotopes ^{185,187}Hg which is planned for next year. A 80-μs isomer was also observed in ^{186}Hg. The analysis of its decay is currently underway.

B. FUSION OF HEAVY IONS

The availability of high-quality beams with masses $A \gtrsim 60$ and with energies sufficient to overcome the Coulomb barrier for even the heaviest targets, has resulted in increased study of the fusion process in such heavy systems. These efforts represent a natural extension of previous work with lighter projectiles that has been done in past years with the tandem accelerator. Of particular interest is whether nuclear structure effects are observed in the fusion of two such heavy ions, as well as the detailed nature of the fusion dynamics near and above the fusion barrier. A recently developed electrostatic-deflector system has been used to separate evaporation residues near 0° from the beam particles. Nuclei far from the line of stability have been produced and their delayed α activity has been studied after implantation in a surface-barrier detector. In addition, the average atomic charge states of evaporation residues have been measured using this deflector system. When coupled with the delayed-alpha-activity measurements we can now study the probability for compound nuclear survival with cross sections in the microbarn region.

To gain information on the relaxation dynamics following the initial contact of two fusing ions (for which there exists little data) we have measured neutron spectra and neutron multiplicity distributions in cold fusion reactions. Comparison with statistical-model calculations suggest that there is a suppression of neutron emission. This may possibly be related to trapping in a superdeformed well as the highly deformed initial state relaxes to the equilibrium shape.

a. Fusion of ^{64}Ni + ^{112,114,116,118,120,122,124}Sn (W. S. Freeman, H. Ernst, D. F. Geesaman, W. Henning, W. Kühn, F. W. Prosser,* J. P. Schiffer, and B. Zeidman)

Detailed measurements of evaporation residue yields following fusion reactions for the ^{64}Ni + Sn system have been obtained. Excitation functions for ^{64}Ni ions incident on the even-mass Sn isotopes were measured over the energy range $235 < E_{lab} < 310$ MeV. (See Fig. II-3.) An electrostatic deflector placed after the target was used to separate the evaporation residues emerging from the target near $\theta_{lab} = 0°$ from the intense flux of beam particles. An improved detector allowed measurements of angular distributions at up to four angles in a plane perpendicular to the deflection plane. When combined with our previous measurements using ^{58}Ni projectiles on the same Sn isotopes, the compound nuclei produced varied in neutron number by 18 neutrons, a change of 20%. We find that the maximum yields for all compound nuclei occur near 170--180 MeV (c.m.) with

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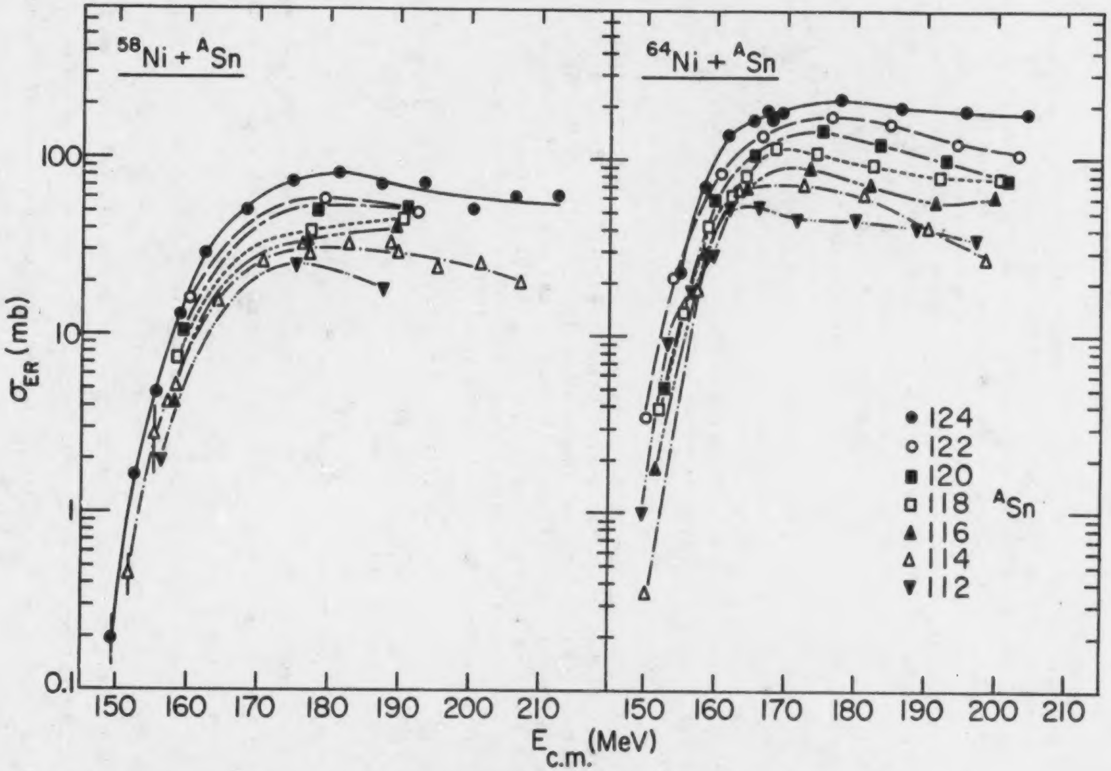

Fig. II-3. Evaporation residue cross sections for ^{58,64}Ni fusing with the even-mass Sn isotopes (A = 112-124). Lines are drawn only to guide the eye.

the maximum cross sections increasing by about one order of magnitude from ^{58}Ni + ^{114}Sn to ^{64}Ni + ^{124}Sn. (See Fig. II-4.) These results allow a systematic study of compound nucleus survivability in systems for which fission competition becomes increasingly important. Related topics of current interest include possible entrance channel effects and whether an "extra-push" energy is needed to achieve fusion in such heavy systems. To further understand the fusion process, we plan to extend our study of the ^{64}Ni + Sn system by measuring fission excitation functions over the same energy range.

b. Fusion of ^{58}Ni + ^{112,114,116,118,120,122,124}Sn (W. S. Freeman, H. Ernst, D. F. Geesaman, W. Henning, T. J. Humanic, W. Kühn, F. W. Prosser,* J. P. Schiffer, and B. Zeidman)

We have measured, at selected energies, the angular distributions of the evaporation residue yield from the fusion of ^{58}Ni with the even-mass Sn isotopes using our improved ΔE-E detector assembly and electrostatic deflector. These measurements allowed us to fix the absolute normalizations of our more extensive $\theta_{lab} = 0°$ excitation function which we had obtained with our earlier, single ΔE-E counter. As a result, we were able to compare excitation functions leading to the same compound nucleus for ^{58}Ni + ^{124}Sn and ^{64}Ni + ^{118}Sn. The excitation functions for the two entrance channels have similar shapes with the ^{64}Ni + ^{118}Sn data having slightly large cross sections above the barrier. The implications regarding the statistical model and possible entrance-channels effects are currently being assessed.

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c. Fission of ^{64}Ni + ^{112,114,116,118,120,122,124}Sn (W. S. Freeman, D. F. Geesaman, W. Kühn, G. Rosner, J. P. Schiffer, and B. Zeidman)

We have recently begun a series of measurements of the fission yields from ^{64}Ni + Sn. These results, when combined with our evaporation residue (ER) cross section measurements for the same systems, will give information on the complete fusion (fission + ER) cross sections near and above the classical fusion barrier. Of particular interest is whether the

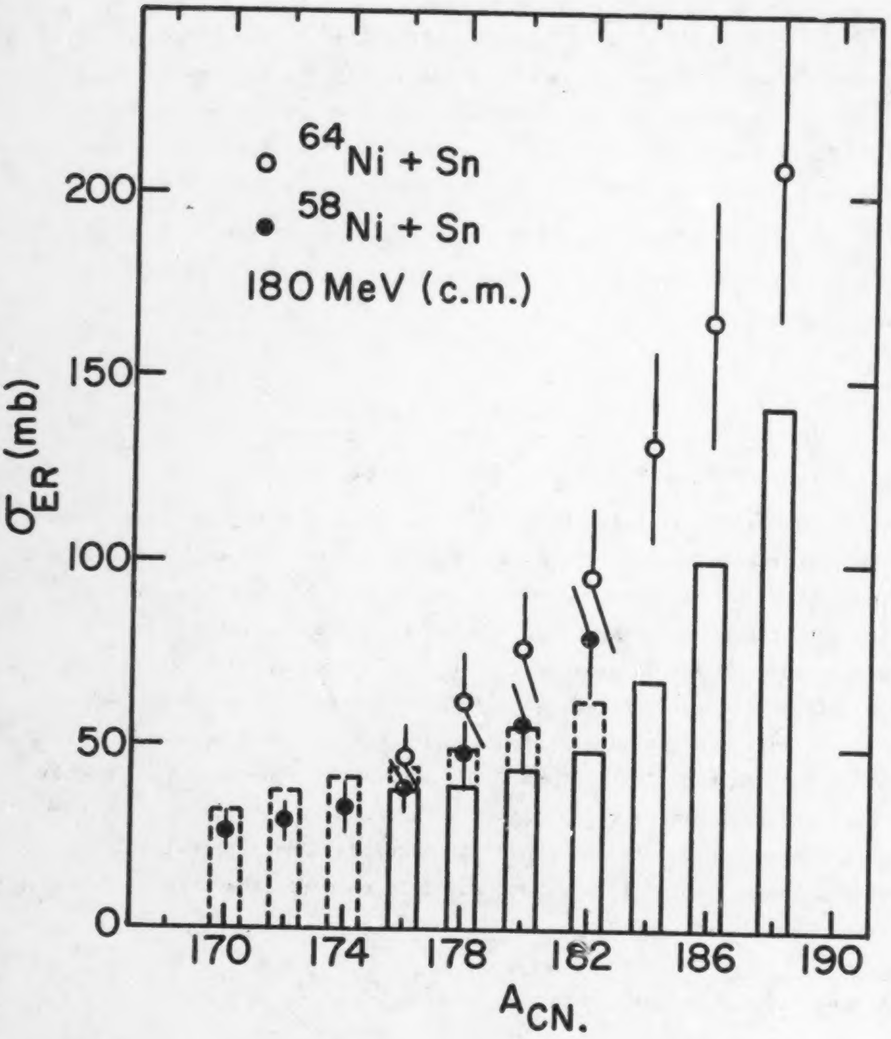

Fig. II-4. Values of σ_{ER} as a function of the compound nucleus mass for ^{58,64}Ni+Sn at E_{cm} = 180 MeV. The open (filled) circles denote ^{64}Ni(^{58}Ni) as the projectile. The solid (broken)-line histograms are the results of statistical-model calculations with ^{64}Ni(^{58}Ni) as the projectile.

observed target (or compound nucleus) mass dependence of the ER cross sections above the barrier reflect differences in the fusion cross sections or differences in the fission competition. To date, one experiment has been performed at incident energies of E_{lab} = 275 and 320 MeV for which the data analysis is in progress.

d. Delayed Alpha-Decay of Evaporation Residues Formed in Fusion Reactions (W. S. Freeman, D. F. Geesaman, W. Henning, W. Kühn, G. Rosner and B. Zeidman)

Delayed alpha decays of the evaporation residues formed following the complete fusion of two heavy ions were observed after their implantation in silicon surface-barrier detectors placed near $\theta_{lab} = 0°$. The electrostatic-deflector system used in our fusion cross-section measurements was utilized to separate the evaporation residues from the beam. Measurement of the delayed alpha energies and lifetimes provides a powerful additional means of particle identification and allows the measurement of lower evaporation residue cross sections. To ascertain the sensitivity of this technique with our present experimental configuration, we searched for delayed activity using ^{58}Ni and ^{37}Cl beams bombarding several targets spanning a broad mass range. The heaviest target-projectile combination for which we observed delayed alpha activity was ^{37}Cl + ^{171}Yb which forms the compound nucleus ^{208}Fr. These results showed background contributions in the α-particle spectrum at a cross-section level of ~2 μb, two orders of magnitude better than our sensitivity using the standard ΔE-E method. Additionally, α-decay measurements have been made following the fusion of ^{58}Ni + ^{112,114}Sn which form the proton-rich compound nuclei ^{170,172}Pt. These nuclei are in a region where there is little information with regard to masses or lifetimes. The data are presently being analyzed.

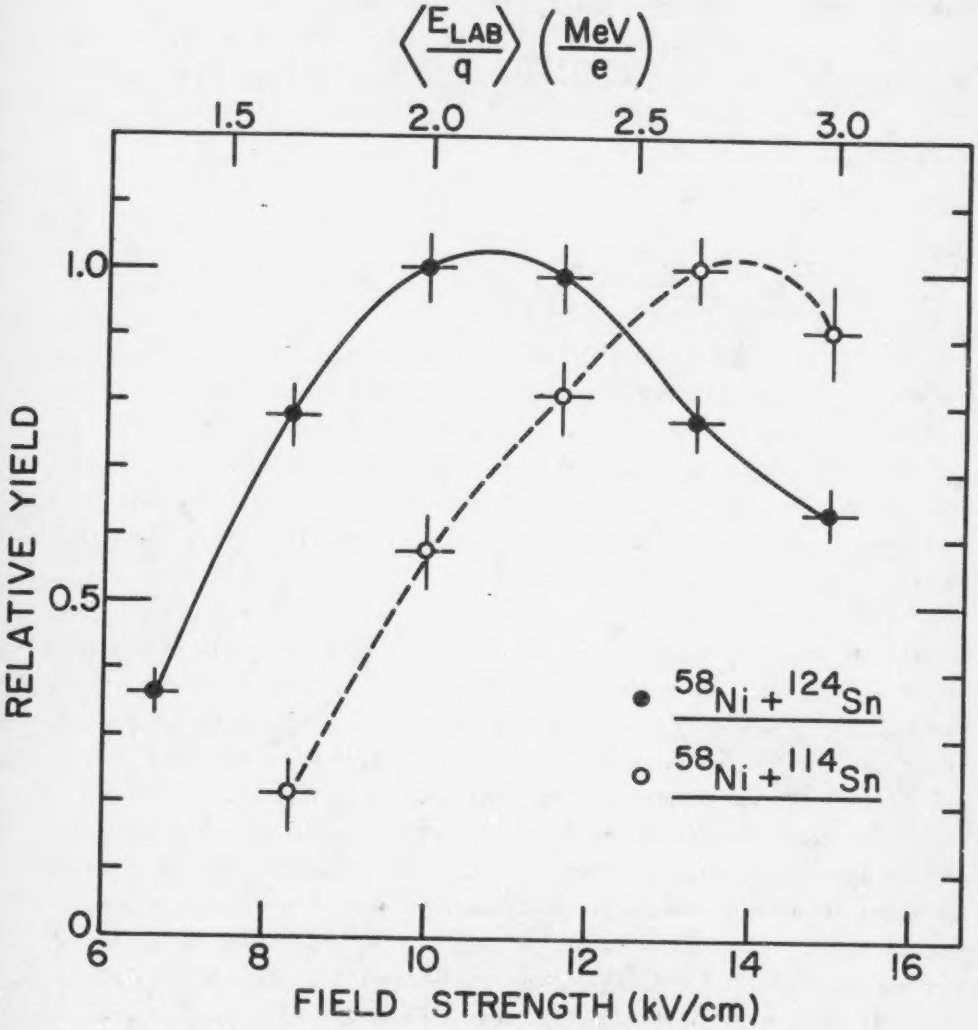

Fig. II-5. The relative evaporation residue yield for $^{58}Ni + ^{114,124}Sn$ as a function of the deflector electric field strength (lower scale) and the average energy-to-charge state ratio (upper scale for E_{lab}^{inc} = 281 MeV.

e. Atomic Charge States of Evaporation Residues (W. S. Freeman, D. F. Geesaman, W. Henning, W. Kühn, F. W. Prosser,* J. P. Schiffer, and B. Zeidman)

In the course of our measurements of evaporation residues formed in heavy-ion fusion reactions (e.g. Ni + Sn), we have employed an electrostatic deflector after the target to separate the low-energy, highly-charged fusion products from the beam. The deflector separates particles according to their charge-to-energy ratio. A knowledge of the average energy of the evaporation residues, which is set by the kinematics of the fusion reaction, together with the known experimental geometry then enables a determination of the average atomic charge state. (See Fig. II-5.) We find charge states for Ni + Sn fusion products that are 6--13 units higher than the equilibrium value expected for stripping in the target (at $E_{lab}^{inc}(Ni) = 280$ MeV). This suggests that nuclear decays after the target foil (e.g. internal conversion and Auger electrons) play an important role. As has been previously realized, these anomalously high charge states have potential implications for fusion measurements that employ recoil mass spectrometers or velocity filters with additional focussing elements that are sensitive to the atomic charge state.

We plan to extend our fusion cross-section measurements, using the deflector, to heavier systems. As a byproduct, these measurements will also provide additional information on the average atomic charge states of these heavier evaporation residues.

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f. Prompt Compound-Nuclear K X-rays in Fusion Reactions Induced by a Heavy Projectile (H. Ernst, W. Henning, C. N. Davids, W. S. Freeman, T. J. Humanic, M. Paul,* and S. J. Sanders†)

The limits of complete fusion and compound-nucleus formation in a nuclear reaction induced by a heavy projectile are currently of great interest. We have studied prompt K X-rays in compound-nuclear reactions induced by a heavy projectile, by determining total production cross sections and multiplicities of K X-rays for the systems $^{32}S + ^{116,120,124}Sn$ from X-ray singles, X-ray--X-ray coincidences, and direct evaporation residue yields over the incident energy range 130 MeV $< E_{lab} <$ 202 MeV. We find a slow dependence of the multiplicities and cross sections on target mass and incident energy, establishing the prompt K X-ray yields as a reliable indicator of the complete fusion cross section behavior induced by a heavy projectile in this mass region. This work has been recently completed and published in Physics Letters.

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†Yale University, New Haven, Connecticut.

g. Suppression of Neutron Emission in 'Cold' Heavy-Ion Fusion

(W. Kühn, P. Chowdhury, R. V. F. Janssens, T. L. Khoo, F. Haas,* J. Kasagi,* and R. M. Ronningen*)

In "cold" heavy-ion fusion reactions, where the excitation energy is low ($E^* < 50$ MeV), the relaxation of the initially highly-deformed nucleus may be influenced by shell effects. For example, the system may be trapped in a secondary minimum in the potential energy surface corresponding to a larger deformation than normally observed near the ground state. We have studied the system $^{64}Ni + ^{92}Zr$, forming the compound system ^{156}Er with $E^* = 46$ MeV. Measurements have been made of the relative yields of the neutron-emission channels (Fig. II-6) and of the neutron spectra corresponding to different γ-sum energies (Fig. II-7). When compared with the results of statistical model calculations, with parameters constrained to fit all available data, the experimental 2n/3n ratio is ~ 38 times larger. Thus there seems to be a suppression of neutron emission. One possible reason for this is that there is trapping in a potential well, as described above, for a time longer than that for neutron emission. The available energy for neutron emission is then reduced, leading to the emission of fewer neutrons than might otherwise have been expected.

If this speculation is correct, there are several consequences which can be experimentally observed, e.g. in the energy distribution of the continuum γ-ray spectrum. Future experiments will be directed towards the search for the evidence necessary to confirm the suggestion of deformation traps.

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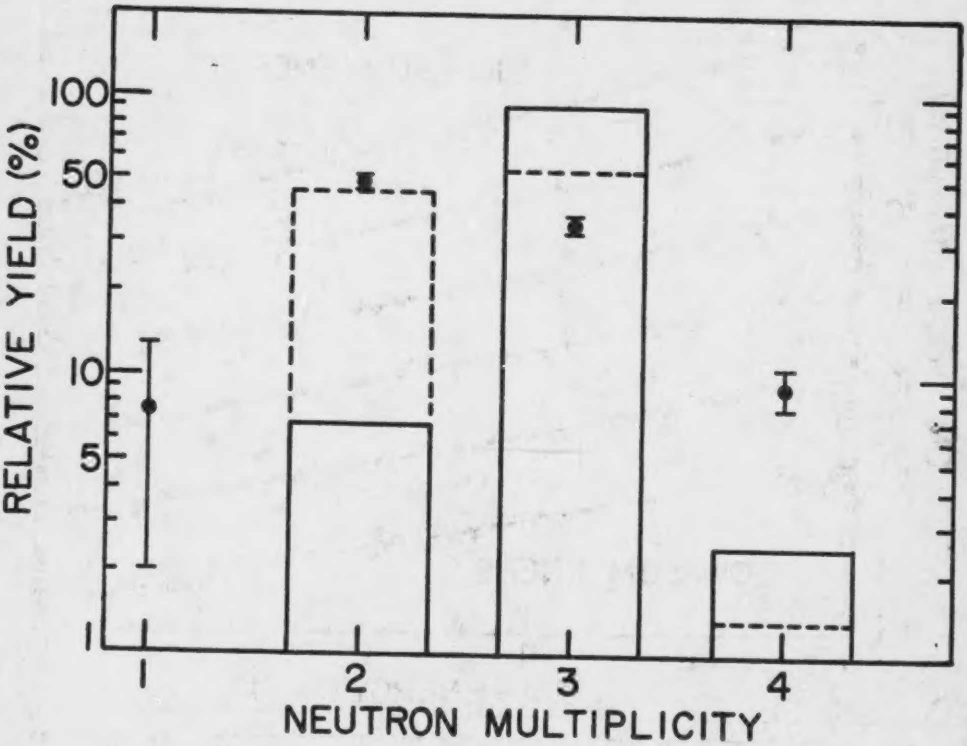

Fig. II-6. Comparison of experimental (open circles) neutron multiplicity distribution with those from statistical-model calculations using the normal (solid bars) and elevated (dashed bars) yrast lines.

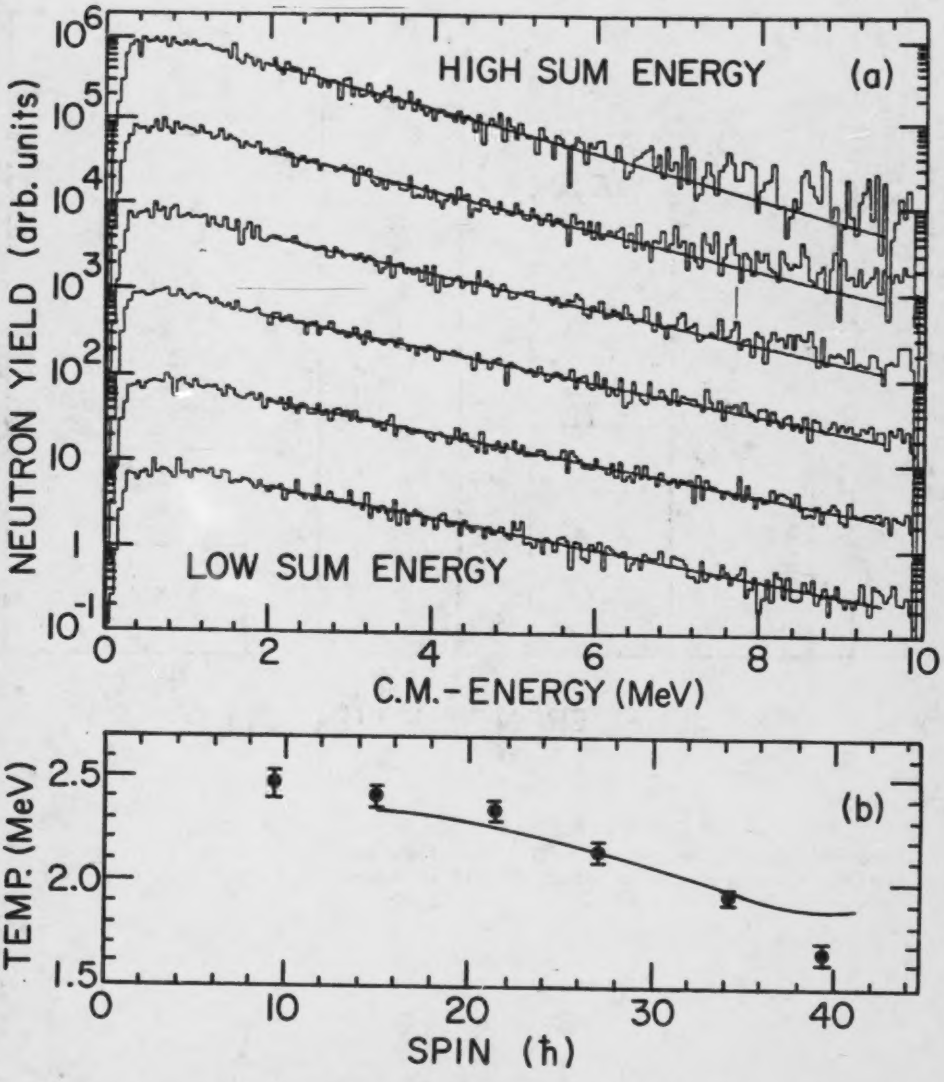

Fig. II-7. (a) Neutron spectra, measured at 0°, for six different gamma-ray sum energy slices. The straight lines represent fits with an exponential function. Deviations from the exponential shape at high sum energy are due to contamination from isomeric gamma rays. (b) Temperatures, derived from the fits in (a), as a function of mean entry line spin corresponding to the different sum slices. The solid line represents results from CASCADE calculations, using an yrast line elevated ~10 MeV with respect to the known one.

C. REACTION MECHANISMS AND DISTRIBUTION OF REACTION STRENGTHS

Studies of reaction mechanisms and distribution of reaction strengths have continued to be extended to higher energies, heavier projectiles, and heavier target nuclei as the accelerator capability has increased. Transitions to distinct final states produced in reactions induced by both lighter projectiles (e.g. ^{16}O) and heavier projectiles (e.g. ^{37}Cl) have been studied to better understand the energy and projectile dependence of direct processes and the transition from quasielastic to strongly-damped processes. Velocity spectra of individually-resolved evaporation residue-like masses have been used in both singles and coincidence measurements to obtain evidence of significant cross sections for incomplete fusion processes at higher bombarding energies for some projectile-target systems.

a. Reactions to Resolved States and Nonfusion Channels for $^{16}O + {}^{48}Ca$ at $E_{lab} = 158.2$ MeV (T. J. Humanic, H. Ernst, W. Henning, and B. Zeidman)

Elastic scattering, inelastic scattering and single-nucleon transfer cross sections to resolved states were measured for the $^{16}O + {}^{48}Ca$ system at $E_{lab} = 158.2$ MeV. In addition the total nonfusion reaction cross section was determined. This study is part of an investigation of energy dependence of the reaction cross sections in the $^{16}O + {}^{48}Ca$ systems and a test of the DWBA model as well as other reaction models. Qualitative agreement between the experimental results and DWBA predictions was found for a number of resolved states. The results have been published in Physical Review.

b. Elastic Scattering and Single-Nucleon Transfer Reactions Induced by ^{16}O on ^{40}Ca at $E_{lab}(^{16}O) = 150$ MeV (G. Stephans, D. G. Kovar, H. Ikezoe, J. Kol~~ata,* R. Pardo,~~ K. E. Rehm, G. Rosner, and R. Vojtech*)

Angular distributions for elastic and inelastic scattering, and for the single-nucleon transfer reactions (^{16}O,^{15}O), (^{16}O,^{15}N), (^{16}O,^{17}O), and (^{16}O,^{17}F) to low-lying states of the projectile- and target-like ejectiles have been measured at $E_{lab}(^{16}O) = 150$ MeV using the split-pole magnetic spectrograph. Using beams from the tandem-linac accelerator, energy resolutions of $\approx$175 keV were obtained. Similar data have been

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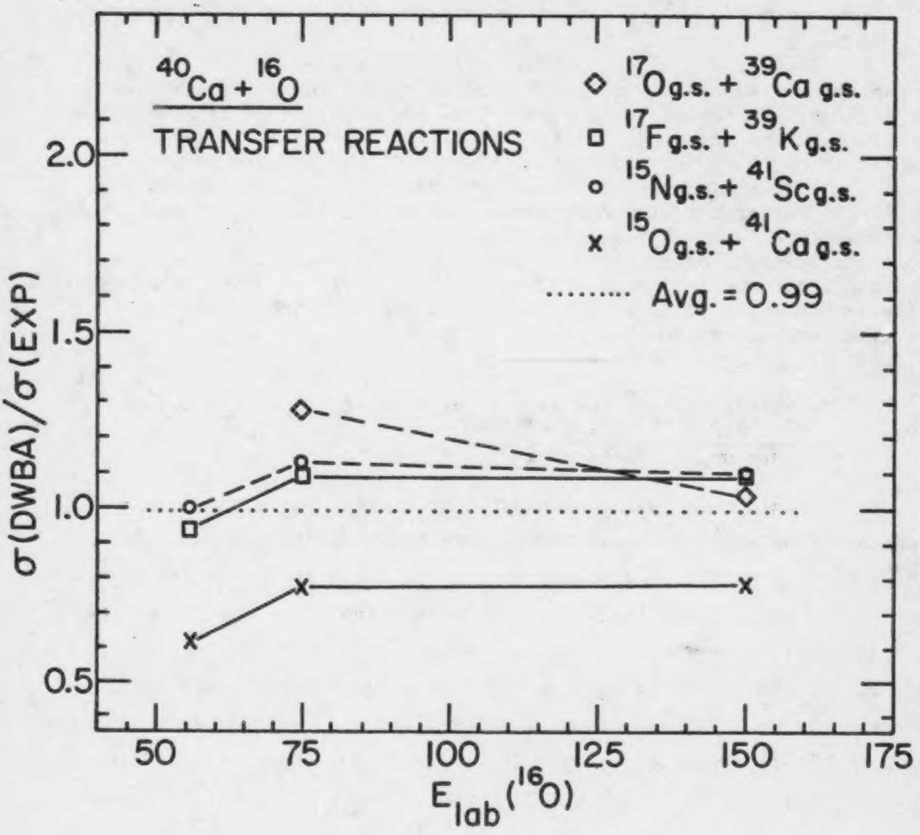

Fig. II-8. Ratio of integrated DWBA cross sections to experimental cross sections for all single-nucleon transfers to projectile-target ground states are plotted versus ^{16}O bombarding energy. Results for 56 and 75 MeV are from Ref. 1 and for 150 MeV are from the present study.

obtained at lower energies[1] and the present data play an important role in establishing the cross-section behavior as a function of bombarding energy. For the elastic and inelastic scattering of interest is the apparent increasing importance of the inelastic excitation of the projectile and questions regarding the importance of coupled-channel effects. For the transfer reactions the interest is in how well DWBA (CCBA) calculations reproduce the energy dependence of the cross sections at bombarding energies significantly above the Coulomb barrier. The data have been analyzed and compared with preliminary DWBA calculations. How well DWBA predicts the cross section behavior is shown in Fig. II-8 when the ratios of integrated DWBA cross sections to experimental cross sections for all single-nucleon transfers linking to projectile-target ground states are plotted. The trend toward overprediction by the DWBA, which was indicated by the lower energy data, is not seen in our preliminary analysis of the higher-energy data of the present study. This result differs from that found for ^{16}O or ^{208}Pb, when a roughly monotonic trend of underprediction at low bombarding energies and overprediction at higher energies was reported.[2] However, the present work is similar to the analysis of ^{16}O on ^{48}Ca, where the $\sigma(DWBA)/\sigma(exp)$ ratio was found to be essentially identical at 56 and 158.2 MeV beam energies.[3] Future studies of the increasing importance of inelastic scattering and transfer reactions to unbound states of the projectile-like ejectiles and the projectile dependence of direct reaction processes involving heavier projectiles are being planned.

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[1] E. Rehm et al., Phys. Rev. C 25, 1915 (1982); D. Kovar et al., Bull. Am. Phys. Soc. 22, 564 (1978); C. Olmer et al., Bull. Am. Phys. Soc. 23, 941 (1978).

[2] S. C. Pieper et al., Phys. Rev. C 18, 180 (1978); C. Olmer et al., Phys. Rev. C 18, 205 (1978).

[3] T. J. Humanic et al., Phys. Rev. C 26, 993 (1982).

c. Measurements of Evaporation Residues Produced in $^{16}O + ^{24}Mg$ at $4 < E_{lab}(^{16}O) < 9.5$ MeV/A (D. G. Kovar, R. R. Betts,* P. Chowdhury, D. Henderson,* T. J. Humanic, H. Ikezoe, R. V. F. Janssens, W. Kühn, G. Rosner, B. Wilkins,* and K. L. Wolf*)

Time-of-flight singles measurements resolving the individual masses of the evaporation residues were performed at $E_{lab}(^{16}O) = 59.5$ MeV to complete measurements begun last year.[1] Results of these measurements showed that the centroids of the velocity spectra of evaporation residues at 59.5 MeV are consistent with that expected for complete fusion, whereas those at 100 MeV and 150 MeV showed deviations of ~2% and 5%, respectively. Comparisons of the predictions of the evaporation code LOLITA with the experimental results indicate that at $E_{lab}(^{16}O) = 59.5$ MeV. The velocity spectra, angular distributions, and to a somewhat lesser degree the mass distribution are well reproduced. At $E_{lab} = 150$ MeV the centroids of the velocity spectra of evaporation residues are poorly reproduced and if one performs a detailed comparison as function of angle only ~600 mb of the ~950 mb of evaporation residue-like cross section is consistent with complete fusion. A coincidence measurement of individual mass residues with protons and alphas was performed at $E_{lab}(^{16}O) = 150$ MeV in an attempt to distinguish more quantitatively the contributions of incomplete fusion processes by observations of energetic protons and alphas which are inconsistent with statistical evaporation. The results of measurements at four angles (23°, -8°, -18°, and -28°) for light-particles and one angle ($\theta_{lab} = 8°$) for the residue have been analyzed. Shown in Fig. II-9 are the alpha-particle velocity spectra ($\theta_L = -18°$) observed in coincidence with the various final particle masses detected at $\theta_L = 8°$. Evidence for high energy (e.g., beam velocity) protons and alphas is clearly observed in the measurements and comparisons with model predictions for complete fusion are being made at the present time. Pending the results of the analysis, a program of measurements to distinguish incomplete and complete fusion processes via coincidence measurements may be indicated. Such information would be of interest since at the present time quantitative cross sections for incomplete and complete fusion cross sections at higher energies are almost nonexistent.

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*Chemistry Division, ANL.

[1] T. Humanic et al., Bull. Am. Phys. Soc. 27, 478 (1982).

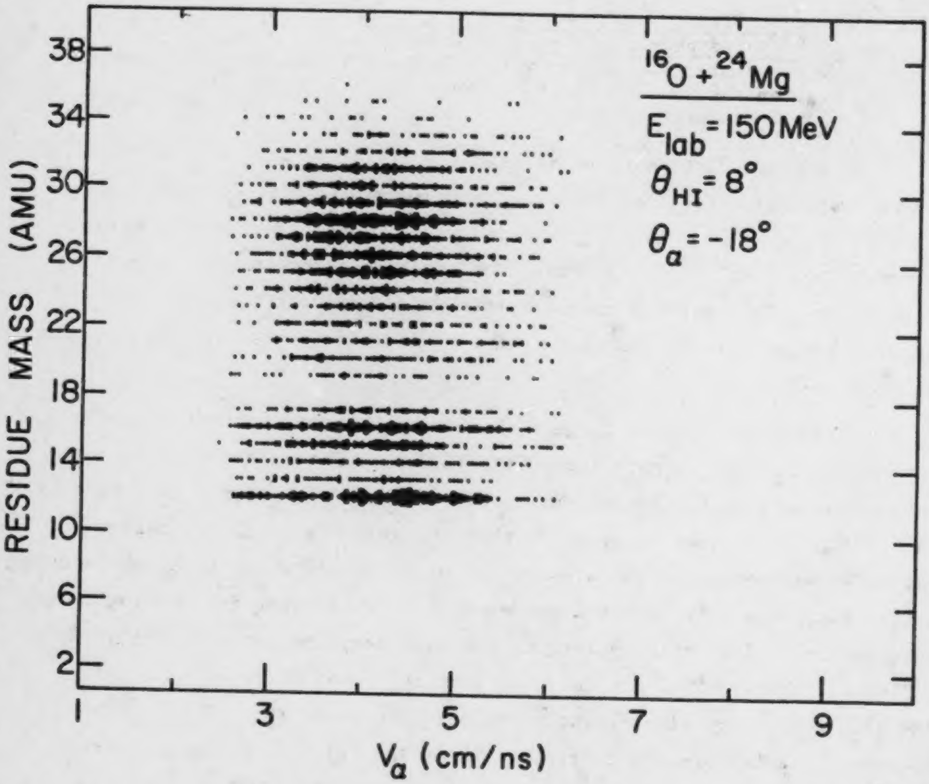

Fig. II-9. Velocity spectrum of alpha particles (θ_{α} = -18°) detected in coincidence with the various mass heavy-ion products observed at θ_{HI} = 8°.

d. **Time-of-Flight Measurements of Evaporation Residues Produced in ^{28}Si-Induced Reactions** (G. Rosner, D. G. Kovar, P. Chowdhury, D. Henderson,* H. Ikezoe, R. Janssens, W. Kühn, G. Stephans, B. Wilkins,* J. Hinnefeld,† J. Kolata,† and F. Prosser, Jr.‡)

Angular distributions of velocity cross sections $1/v^2\ d^2\sigma/dv d\Omega$ of fusion evaporation residues (ER) were measured for ^{16}O(E_{Lab} = 150 MeV) and ^{28}Si (E_{Lab} = 175, 214, 219, and 263 MeV) induced reactions on targets of ^{12}C, ^{24}Mg, ^{27}Al, ^{28}Si and ^{40}Ca. The reaction products were identified by mass ($m \sim Et^2$) using 2 channel-plate detectors (start,stop) and a surface barrier detector (stop,E). A typical velocity versus mass spectrum is shown in Fig. II-10.

Previous studies suggest that for asymmetric systems (light projectile, heavier target) incomplete fusion or incomplete momentum transfer occurs at $E_{lab}/A \gtrsim 5$ MeV. The average ER velocities have been reported to be appreciably smaller than the velocity of the center-of-mass. The intention of the present set of experiments was to study in more detail the projectile-target dependence of this behavior and to single out entrance channel effects by forming the same compound nucleus ^{56}Ni via ^{16}O + ^{40}Ca and ^{28}Si + ^{28}Si. It is found that the total ER cross sections for ^{28}Si + ^{28}Si are significantly smaller than those for ^{16}O + ^{40}Ca at comparable center-of-mass energies. While the velocity spectra observed for ^{28}Si + ^{28}Si are in good agreement with the predictions of complete fusion calculations (LILITA), those for ^{16}O + ^{40}Ca show significant discrepancies. Both observations indicate that ER formation in ^{28}Si + ^{28}Si is essentially due to complete fusion at the bombarding energies measured, while the excess of ER cross sections in ^{16}O + ^{40}Ca stems from incomplete fusion processes. A comparison with ER velocity cross sections for the other fusion reactions measured is underway.

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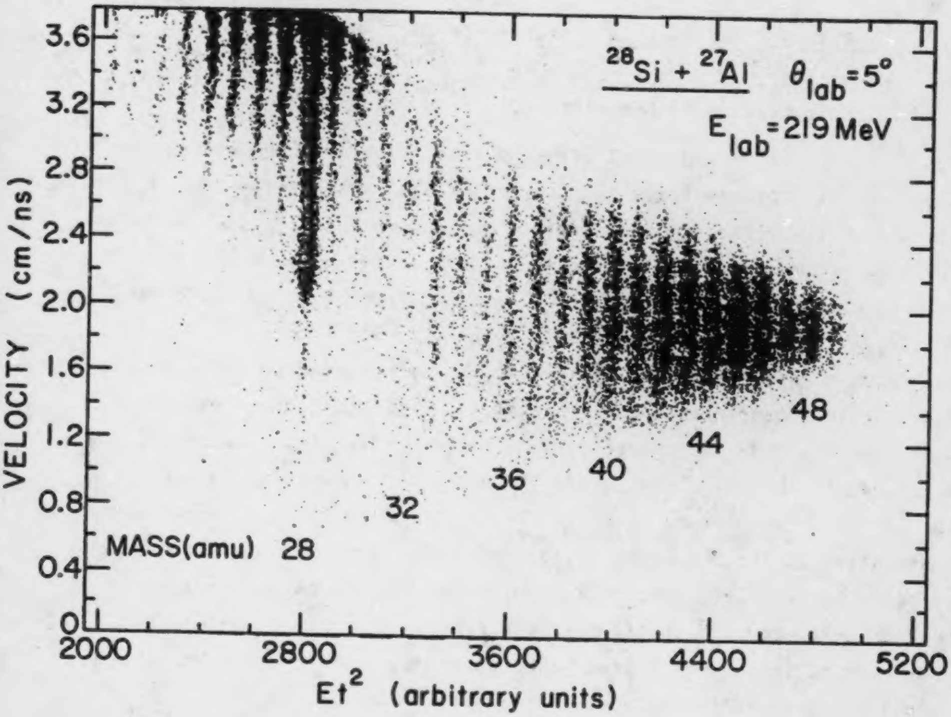

Fig. II-10. Velocity versus mass spectrum of the reaction 219 MeV $^{28}Si + ^{27}Al \rightarrow ER + x$, measured at E_{lab} = 5°. The fusion evaporation residues (ER) are centered around mass 44 amu.

e. Fusion Cross Section Measurements for ^{20}Ne + ^{40}Ca at E_{lab}(^{20}Ne) = 150 and 220 MeV (D. G. Kovar, W. Bohne,* M. Burgel,* Ch. Egelhaaf,* H. Fuchs,* A. Gamp,* K. Grabisch,* H. Homeyer,* H. Morgenstern,* and W. Rauch*)

At the present time large uncertainties exist regarding the experimental cross sections for complete fusion at energies $E_{lab} > 7$ MeV/A because of the presence of incomplete fusion processes. Time-of-flight (TOF) measurements resolving the individual masses allow inspection of the velocity spectra of the evaporation residue-like fragments. For the ^{20}Ne + ^{40}Ca system at E_{lab}(^{20}Ne) = 291 MeV the velocity spectra revealed centroids significantly smaller (~10%) than that expected for complete fusion (i.e., complete momentum transfer), suggesting the presence of contributions from incomplete fusion and providing an indication of their magnitude.[1] In the present study TOF measurements were performed for the ^{20}Ne + ^{40}Ca reaction at E_{lab}(^{20}Ne) = 150 and 220 MeV to establish the systematics of the departure of the centroids of the evaporation residue velocity spectra from that of full momentum transfer a as function of bombarding energy and to attempt to establish the cross sections for complete and incomplete fusion. The experiments were performed at the VICKSI facility at the Hahn Meitner Institüt, Berlin, where the measurements provided unambiguous mass resolutions for the heaviest residues detected ($m < 54$ amu). The analysis of the data is underway at this time. Plans for the future involve extension of these measurements to higher energies ($15 < E_{lab} < 35$ MeV/A) to explore the use of velocity spectra as an observable for distinguishing complete and incomplete fusion processes.

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*Hahn Meitner Institüt, Berlin, Germany.

[1] H. Morgenstern et al., Phys. Lett. 113B, 463 (1982).

f. Study of Direct Reactions in the System $^{37}Cl + ^{208}Pb$ at E_{lab} = 250 MeV (K. E. Rehm, W. Kutschera, and M. Paul*)

In order to investigate the transition from quasielastic to deep inelastic reactions we are studying the interaction between different projectiles and ^{208}Pb at energies not too high above the Coulomb barrier. In a first experiment we investigated the system $^{37}Cl + ^{208}Pb$. With an energy resolution of ~450 keV it was possible to measure the angular distributions of elastic scattering and for the excitation of the first excited states in $^{37}Cl(1/2^+)$ and $^{208}Pb(3^-)$. The results are shown in Fig. II-11. The solid lines represent optical-model (elastic) and DWBA (inelastic) calculations performed with the code PTOLEMY.[1] From the least-squares fit to the angular distribution for elastic scattering the following optical potential parameters are obtained: $-V = 13.1$ MeV, $r_o =$ 1.3 fm, $a = 0.645$ fm, $-W = 5.5$ MeV, $r_o' = 1.446$ fm, $a' = 0.223$ fm. For the DWBA calculations no parameters have been adjusted. The B(EL) values were taken from the literature and the same mass and charge deformation lengths have been used. The transfer reactions are strongly dominated by the neutron pickup channels ($^{37}Cl,^{38}Cl$) and ($^{37}Cl,^{39}Cl$), whereas deep inelastic scattering reactions are observed mainly in the proton transfer channels (^{37}Cl,S), (^{37}Cl,P) and (^{37}Cl,Al).

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*Hebrew University, Jerusalem, Israel.

[1] M. H. Macfarlane and S. C. Pieper, ANL Report ANL-76-11, Rev. 1.

g. Spectroscopic Studies of ^{234}Th with the ($^{18}O,^{16}O$) Reaction

(K. E. Rehm, D. Frekers, T. Humanic, R. V. F. Janssens, T. L. Khoo, and W. Kutschera)

The ground-state rotational band of ^{234}Th has been investigated with particle-γ techniques using the split pole magnetic spectrograph. Outgoing particles from the reaction $^{18}O + ^{232}Th$ at E_{lab} = 130 MeV were momentum analyzed in the spectrograph at a solid angle of 5.6 msr and detected by the position-sensitive ΔE-E ionization chamber in the focal plane. Ray-tracing techniques were used to correct the ΔE and Be signals. Gamma rays coincident to different particle groups in the outgoing channel were detected in an 80-cm^3 or cc GeLi detector, positioned

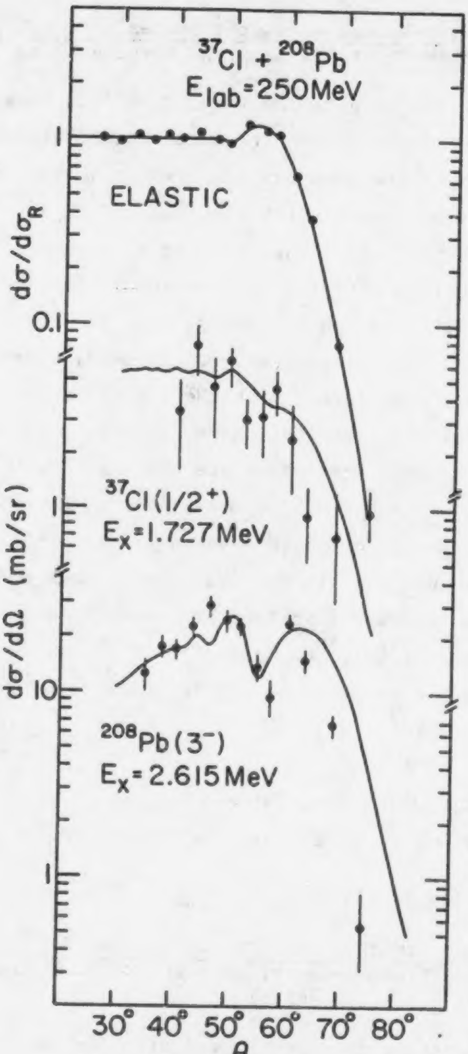

Fig. II-11. Angular distributions for elastic scattering and inelastic excitation of the $1/2^+$ state in ^{37}Cl and the 3^- state in ^{208}Pb, respectively, as measured in the system ^{37}Cl + ^{208}Pb at E_{lab} = 250 MeV.

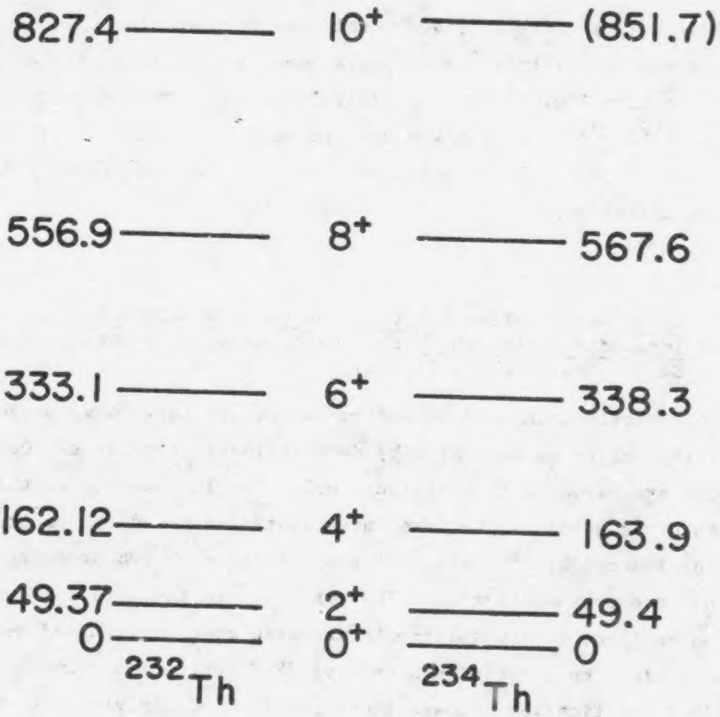
827.4
10⁺
(851.7)
556.9
8⁺
567.6
333.1
6⁺
338.3
162.12
4⁺
163.9
49.37
2⁺
49.4
0
0⁺
0
232Th
234Th

Fig. II-12. Energy levels for ^{232}Th and ^{234}Th.

10 cm from the target. Previously only the 2^+ state in ^{234}Th has been unambiguously identified. In our experiment states up to I = 8(10) could be observed (see Fig. II-12). An attempt to increase the momentum transfer using the (^{17}O,^{15}O) reaction was not successful. In future experiments we plan to replace the GeLi detector with an electron spectrometer for higher detection efficiency.

h. Large Neutron-Transfer Cross Sections Observed in ^{58}Ni and ^{48}Ti Induced Reaction on ^{208}Pb (K. E. Rehm, D. Kovar, W. Kutschera, G. Stephans, and J. Yntema)

Reactions induced by medium-weight and very heavy projectiles are usually thought to be dominated by deep inelastic reactions. Quasielastic reactions are expected to contribute only a small fraction to the total reaction cross section. We have investigated mass and charge transfer reactions induced by ^{48}Ti and ^{58}Ni projectiles on ^{208}Pb at energies about 25% above the Coulomb barrier. The particles in the outgoing channel were momentum analyzed in the split-pole magnetic spectrograph and detected in the focal plane by a position-sensitive ΔE-E ionization chamber. The particle identification allowed the separation of individual elements and isotopes around ^{48}Ti and ^{58}Ni. Figure II-13 shows a mass spectrum for Z = 28 particles with a mass resolution $\Delta m/m < 6 \times 10^{-3}$. The energy resolution was limited by the ^{208}Pb target thickness (100 μg/cm^2) to about 800 keV. Both ^{58}Ni and ^{48}Ti induced reactions show a deep inelastic reaction component, which is well pronounded especially at forward angles. Quasielastic reactions, however, are not negligible. Figure II-14 shows angular distributions for elastic and inelastic scattering and for the (^{58}Ni,^{59}Ni) and (^{58}Ni,^{60}Ni) reactions, integrated over all excitation energies. The total cross section for 1- and 2-neutron pickup is 260 mb and 62 mb, respectively amounting to about 25% of the total reaction cross section, as estimated from the quarter point angle. Differences in the mass and charge flow observed for ^{48}Ti and ^{58}Ni induced reactions can be explained by the underlying driving potentials.

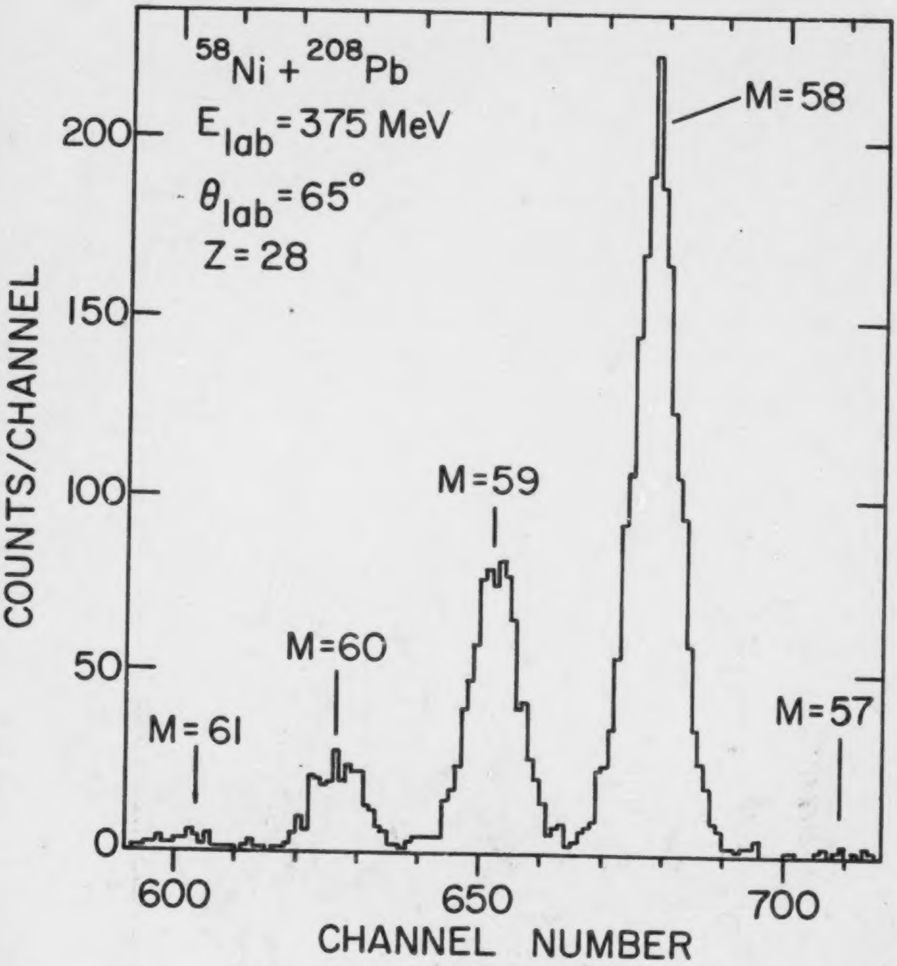

Fig. II-13. Mass spectrum for Z = 28 observed for 375-MeV ^{58}Ni + ^{208}Pb at θ_{lab} = 65°.

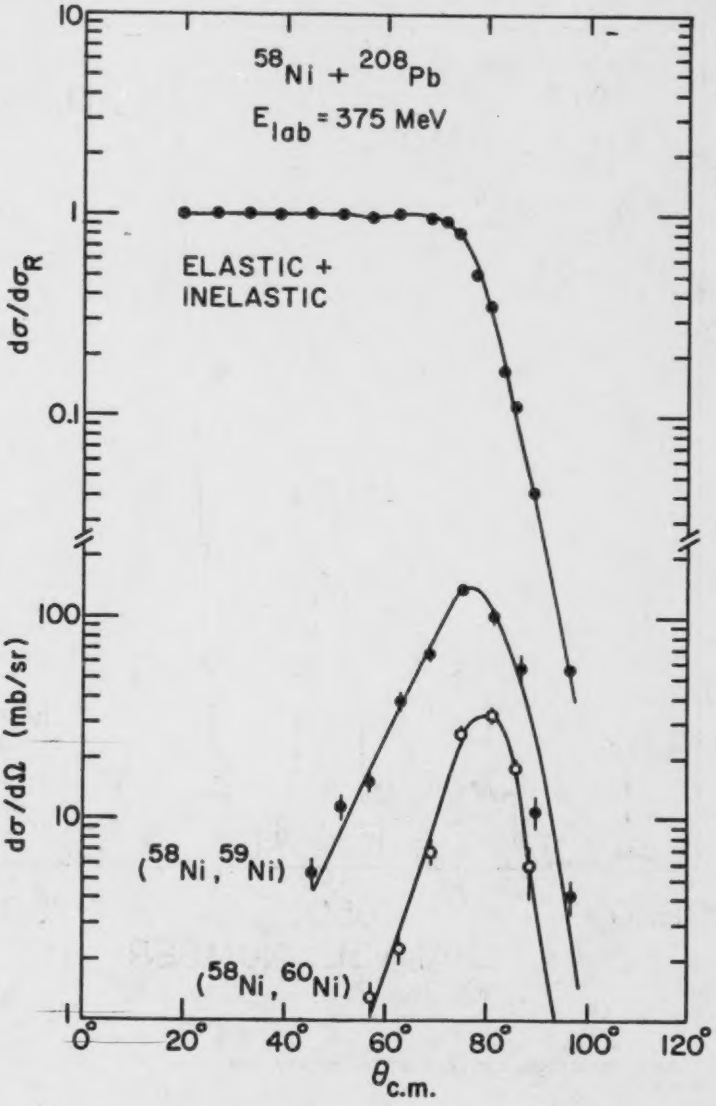

Fig. II-14. Angular distributions for elastic + inelastic (^{58}Ni, ^{59}Ni) and (^{58}Ni, ^{60}Ni) reactions on ^{208}Pb at E_{lab} = 375 MeV.

i. Observation of Characteristic Gamma Rays from Quasi-Elastic and Deep-Inelastic Fragments in the ^{58}Ni + ^{58}Ni Reaction (W. Kühn, P. Chowdhury, R. V. F. Janssens, and T. L. Khoo)

This experiment investigates the transition between quasi-elastic reactions, which are strongly dependent on nuclear structure, and deep-inelastic reactions, which are dominated by statistical features. Encouraged by a preliminary experiment described last year, a more extensive experiment was performed where the gamma sum energy, and the characteristic gamma rays from one and both of the fragments for 345-MeV ^{58}Ni + ^{58}Ni were recorded. The analysis is currently underway. Experiments at other incident energies and involving different target-projectile combinations are planned.

D. ACCELERATOR MASS SPECTROMETRY (AMS)

Over the past few years the technique of AMS has developed into a powerful tool to measure extremely low concentrations (10^{-10} to 10^{-15}) of a variety of long-lived radioisotopes (^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl, ^{41}Ca, ^{44}Ti, ^{59}Ni, ^{60}Fe, ^{129}I). At present about 20 laboratories throughout the world (mainly centered around tandem accelerators) are using this technique. Most of the laboratories have embarked on rather extensive measurements in applied fields (e.g. Geophysics, Hydrology, Archeology, Meteoritics). At Argonne a line more closely related to nuclear physics is pursued. At present, measurements on half-lives (^{44}Ti, ^{60}Fe), exotic ions (doubly-charged negative), and on the detection of natural ^{41}Ca are underway. Both the tandem alone and the tandem-linac system in connection with Enge split-pole spectrographs are used. The higher energies from the linac allow one to extend the measurements to heavier isotopes for better identification. In addition, for some cases the very clean separation technique of fully-stripped ions.

a. Measurement of the Half-Life of ^{44}Ti via Accelerator Mass Spectrometry (D. Frekers, W. Henning, W. Kutschera, K. E. Rehm, R. K. Smither, J. L. Yntema, and B. Stievano*)

The half-life of ^{44}Ti has been measured from the specific activity using the technique of accelerator mass spectrometry. The interest in a remeasurement of the half-life arose from the fact that a previously-performed irradiation of a ^{45}Sc sample with 45-MeV protons had yielded a substantial amount of ^{44}Ti, which could possibly be used for the preparation of a target for future experiments. For the present application of accelerator mass spectrometry, several TiO_2 samples, spiked with ^{44}Ti of about 1.2-μCi total activity, have been prepared and used as sputter targets for injection of a TiO^- beam. ^{44}Ti was accelerated to 80 MeV in the FN tandem and identified in the Enge split-pole spectrograph at $\theta = 0°$. The strong and ever present background contributions from different ion beams with the same magnetic rigidity were effectively eliminated using a second stripper foil in the spectrograph scattering chamber and, by means of two movable shields, blocking all but the 15^+ charge state from entering the focal-plane detector. A typical ΔE-E spectrum obtained during the measurement is shown in Fig. II-15. The concentration of ^{44}Ti in the source material ($^{44}\mathrm{Ti/Ti} = 2 \times 10^{-7}$) was measured with respect to the yield of the ^{46}Ti isotope. Mass-fractionating effects were taken into account by measuring the relative beam currents of

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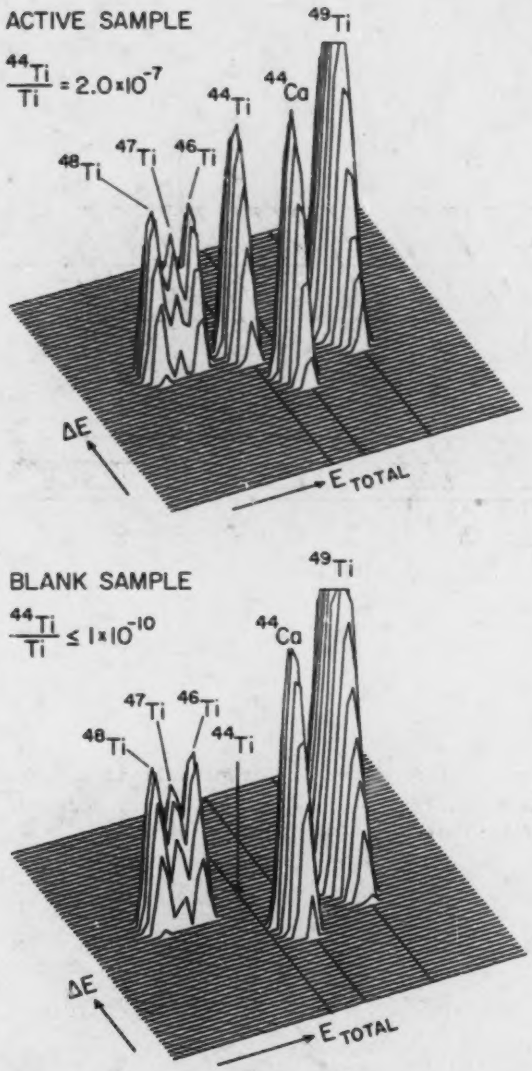

Fig. II-15. An isometric view of the 2-dimensional ΔE-E spectrum for the $Z \approx 22$ region measured with the focal-plane detector of the magnetic spectrograph. The lower part shows the result from a blank sample whereas the upper part was obtained using a ^{44}Ti-spiked sample. The various background components are indicated.

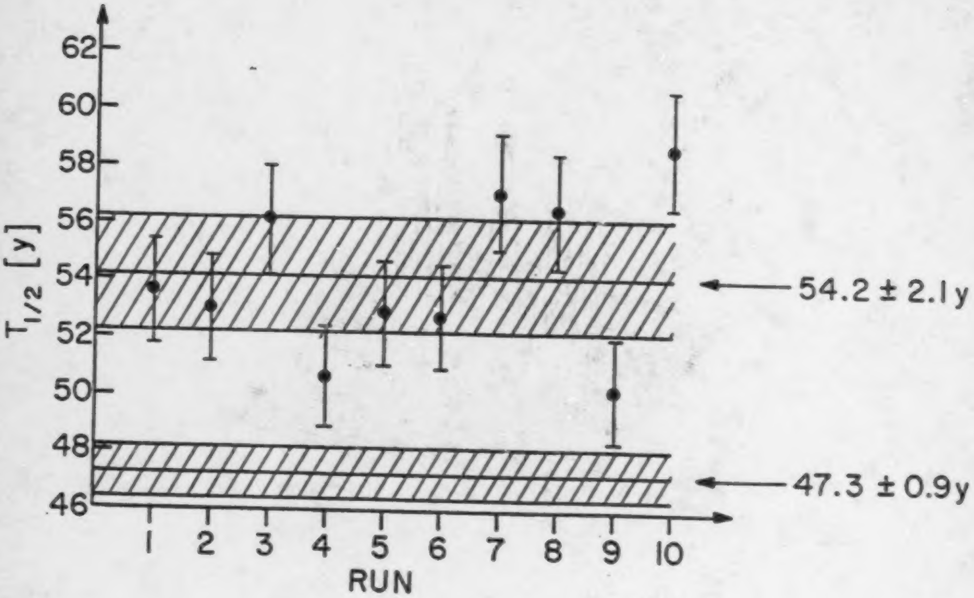

Fig. II-16. The results of ten different half-life measurements, giving a mean value of 54.2 ± 2.1 y. The previously accepted value is indicated by the hatched area around 47.3 y.

the stable Ti isotopes ($^{46-50}$Ti) for equal velocities at the terminal stripper. An overall sensitivity for the ^{44}Ti concentration of 1×10^{-10} was achieved proving accelerator mass spectrometry to be a powerful tool for radioisotope detection even for heavier elements. Our value for the half-life of ^{44}Ti, 54.2 ± 2.1 y, turns out to be slightly higher than the previously accepted value of 47.3 ± 0.9 y (see Fig. II-16).

b. Search for Doubly-Charged Negative Ions via Accelerator Mass Spectrometry

(W. Kutschera, D. Frekers, R. Pardo, K. E. Rehm, R. K. Smither, and J. L. Yntema)

Doubly-charged negative ions would be highly desirable for tandem accelerators since the total energy gain of the ion beam could be substantially increased. The production probability for these exotic ions, however, is known to be extremely low. We have performed an ultrasensitive measurement of the production rate of doubly-charged negative ions in a sputter source using the techniques of accelerator mass spectrometry. If ions fully stripped at the terminal are selected after acceleration in the tandem, an unambiguous energy signature can be derived. Setting the beam transport system to the corresponding rigidities, doubly-charged negative ions can be identified in the Enge split-pole magnetic spectrograph under very clean conditions. In our experiment we have focussed on the investigation of ^{11}B, ^{12}C, and ^{16}O. These elements are known to produce singly-charged negative ions with high probability. Several high-sensitivity measurements were carried out and no doubly-charged negative ions were identified at a level of 10^{-14} to 10^{-15} (with respect to singly-charged negative ions). A search for singly-charged negative ions of He and Ne was also performed. After stripping in the tandem foil, copious amounts of $^{4}He^{2+}$ ions ($>10^3$ per sec) were observed, but no signal from $^{20}Ne^{9+}$ ions in 30 min. He^- is known to have a half-life of 15 μsec which is in the same order of magnitude as the flight time from the ion source to the terminal. It may therefore be concluded that if Ne^-, $^{11}B^{--}{}^{12}C^{--}$ and $^{16}O^{--}$ do exist, their half-life must be much shorter than 1 μsec or the production probability must be greatly suppressed.

c. Accelerator Mass Spectrometry of ^{41}Ca (W. Kutschera, D. Frekers, K. E. Rehm. R. K. Smither, J. L. Yntema, Ma Xiuzeng,* and M. Paul†)

The goal of this experiment is to detect the long-lived radioisotope ^{41}Ca($T_{1/2}$ = 1 × 10^5 yr) at natural concentrations estimated[1] to be as low as ^{41}Ca/Ca = 10^{-15}. Since ^{41}Ca is produced in the earth's crust through thermal neutron capture from cosmic-ray secondary neutrons, a successful method for ^{41}Ca detection would offer numerous geo- and archeochronological applications. In order to reach this goal several problems have to be solved: 1) the isobaric interference of ^{41}K must be removed, 2) the background from stable Ca isotopes must be efficiently suppressed, and 3) the yield of negative Ca ions must be greatly increased. The last problem appears to be the most difficult to solve.

So far the experiments were performed using the tandem accelerator in conjunction with the Enge split-pole spectrograph as a highly sensitive mass spectrometer. A schematic layout of the system is shown in Fig. II-17. ^{41}Ca/Ca ratios were measured from samples in the ion source by identifying and counting 91-MeV ^{41}Ca ions in the split-pole spectrograph and relating this number to a ^{40}Ca current measurement in the split-pole scattering chamber. With a careful consideration of relevant normalizing parameters absolute ratios with a precision around 10% can be measured.

The most convenient end product of any preparatory chemistry is CaO. Therefore we used this material in the ion source. Since Ca does not like to form negative elemental ions (even from metal Ca) one has to use molecular ions. In a first run we tried CaO^- ions with little success. Low yield and interferences from close-lying molecules made a clean identification of ^{41}Ca impossible. Somewhat better was CaH^-. However, K also forms KH^- and hence the ^{41}Ca – ^{41}K interference is not removed. In the second run we used CaH_3^- ions. The output was enhanced by spraying NH_3 onto the CaO samples. Apparently, KH_3^- ions do not form in any detectable quantity which solves the isobaric interference problem completely. This

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†Hebrew University, Jerusalem.

[1] G. M. Raisbeck and F. Yiou, Nature 277, 42 (1979).

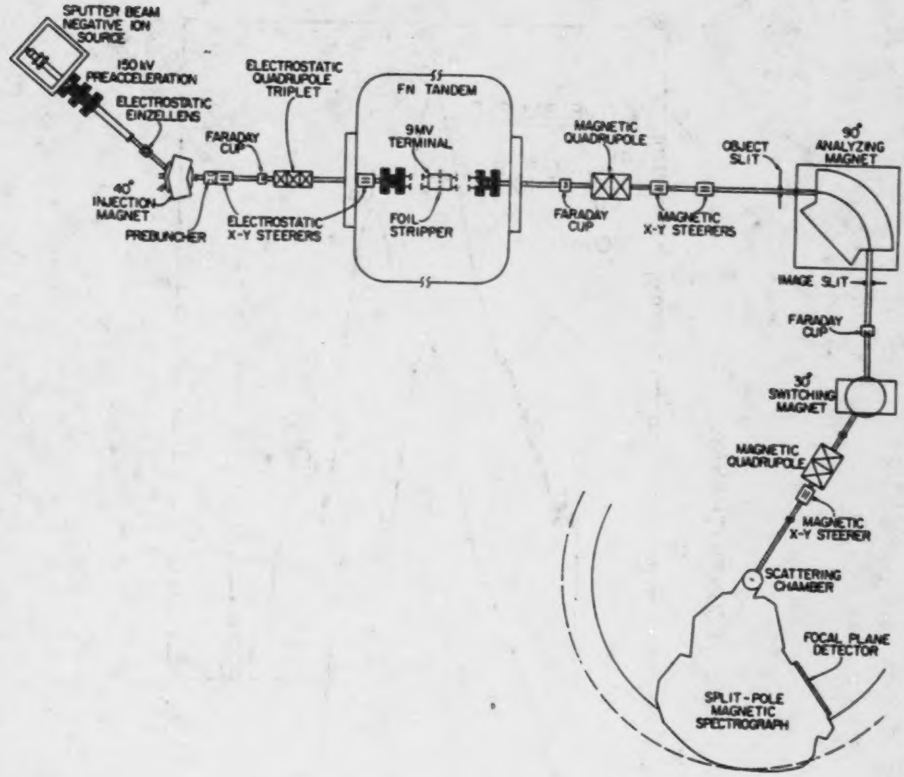
SPUTTER BEAM NEGATIVE ION SOURCE
150 kV PREACCELERATION
ELECTROSTATIC EINZELLENS
40° INJECTION MAGNET
PREBUNCHER
FARADAY CUP
ELECTROSTATIC QUADRUPOLE TRIPLET
ELECTROSTATIC X-Y STEERERS
FN TANDEM
9MV TERMINAL
FOIL STRIPPER
MAGNETIC QUADRUPOLE
FARADAY CUP
MAGNETIC X-Y STEERERS
OBJECT SLIT
90° ANALYZING MAGNET
IMAGE SLIT
FARADAY CUP
30° SWITCHING MAGNET
MAGNETIC QUADRUPOLE
MAGNETIC X-Y STEERER
SCATTERING CHAMBER
FOCAL PLANE DETECTOR
SPLIT-POLE MAGNETIC SPECTROGRAPH

Fig. II-17. Schematic layout of the experimental system used in radioisotope detection with the FN tandem.

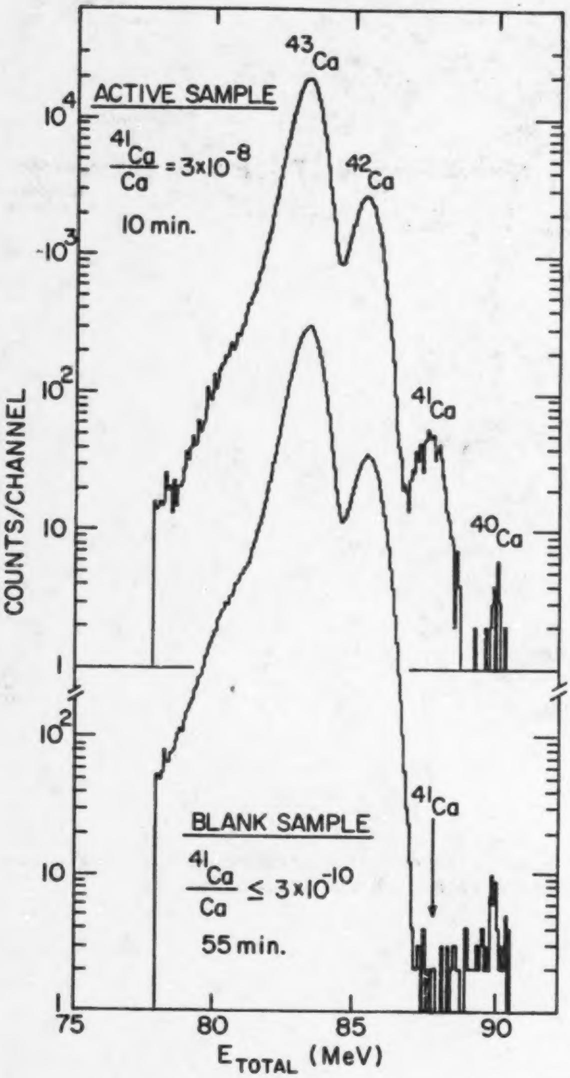

Fig. II-18. Total energy spectra of various Ca isotopes measured in the focal plane detector of the split-pole spectrograph. The measured energy of the ions is approximately 13 MeV lower than the incident energy due to the energy loss in the detector entrance foil.

confirms previous findings of Raisbeck et al.[2]. Figure II-18 shows total energy spectra measured for an enriched ^{41}Ca material and a blank. Strong background peaks of ^{43}Ca and ^{42}Ca appear because $^{41}CaH_3^-$ is injected into the tandem accepting $^{42}CaH_2^-$ and $^{43}CaH^-$ ions as well. By multiple charge changes in the accelerator tubes these ions produce a "white" spectrum of magnetic rigidities after the tandem from which small bins are cut out by the purely magnetic transport system set up to accept $^{41}Ca^{10+}$ ions. An addition of a Wien filter or an electrostatic separator should greatly suppress this degeneracy.

$^{40}Ca^{10+}$ currents of 0.4 nA were measured for normalization. As can be judged from the results of Fig. II-18 we have yet to go a long way to reach the goal of ^{41}Ca/Ca ratios around 10^{-15}. Several approaches will be tried: 1) Ca metal instead of CaO should yield a factor 100 more output of CaH_3- ions. Although factors of 700 have been measured in our laboratory in the past, reproducible conditions have not been established. 2) In order to reach highest sensitivity a background-free condition must be established. We will try two different approaches. One is to use a Wien filter for an isotopic cleanup in the present system. The other is to use the tandem-linac system. Due to the stringent phase-matching requirements, the linac acts as an excellent mass filter. In addition, the increased energy after the linac would allow a much cleaner identification as compared to tandem energies. Assuming an optimistic increase of a factor 1000 for the Ca current and a background-free condition, we would be able to measure a ^{41}Ca/Ca ratio of 1×10^{-15} with one ^{41}Ca count per hour. Such a condition has been achieved in several laboratories for lighter, long-lived radioisotopes (e.g. ^{36}Cl) which, however, easily form negative ions.

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[2] G. M. Raisbeck, F. Yiou, A. Peghaire, J. Guillot, and J. Uzureau, Proc. Symp. on Accel. Mass Spectrometry, Argonne 1981, Argonne Natl. Laboratory Report ANL/PHY-81-1, p. 426.

d. Measurement of the Half-Life of ^{60}Fe Using the Tandem-Linac System as an Accelerator Mass Spectrometer (W. Kutschera, P. J. Billquist, D. Frekers, W. Henning, X. Z. Ma,* L. F. Mausner,† M. Paul,‡ R. Pardo, K.E. Rehm, R. K. Smither, and J. L. Yntema)

The half-life of ^{60}Fe has been measured only once in the past[1] yielding a value of $T_{1/2} = 3 \times 10^5$ y, uncertain by a factor 3. The recent finding[2] of extinct ^{26}Al activity ($T_{1/2} = 7.2 \times 10^5$ y) through the Allende meteorite makes ^{60}Fe potentially interesting as a possible signature of iron peak nucleosynthesis. An improved half-life value for ^{60}Fe could lead to its use as an interesting geo- and cosmochronological tracer in the million-year range. In particular, a measurement of ^{60}Fe in meteorites[3] with the highly-sensitive method of Accelerator Mass Spectrometry (AMS) seems feasible.

We are presently engaged in an experiment to improve the accuracy in the half-life value of ^{60}Fe by measuring both the amount of ^{60}Fe nuclei and the decay rate of a spallation-produced sample using the relation $dN/dt = -\lambda N$. The sample material was produced by irradition of 4.5 g/cm^2 Cu with 18.7 mAh of 193-MeV protons in the Brookhaven Linac Isotope Producer (BLIP). One year after irradiation the iron fraction was chemically extracted. This material contained approximately 10^{15} ^{60}Fe nuclei besides mCi quantities of ^{55}Fe ($T_{1/2} = 2.7$ y) and µCi amounts of ^{59}Fe($T_{1/2} = 45.1$ d). After an additional period of 5 months, the ^{60}Fe content was determined by adding a known amount of stable iron (>100 times the original amount) and measuring the ^{60}Fe/Fe ratio with AMS. For this measurement several 130-mg Fe pellets were put into an improved inverted

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†Brookhaven National Laboratory, Long Island, New York.

‡The Hebrew University of Jerusalem, Jerusalem, Israel.

[1] J.-C. Roy and T. P. Kohman, Can. J. Phys. 35, 649 (1957).

[2] T. Lee, D. A. Papanastassiou and G. J. Wasserburg, Geophys. Res. Lett. 3, 109 (1976); Astrophys. J. 211, L107 (1977).

[3] P.S. Goel and M. Honda, J. Geophys. Res. 70, 747 (1965).

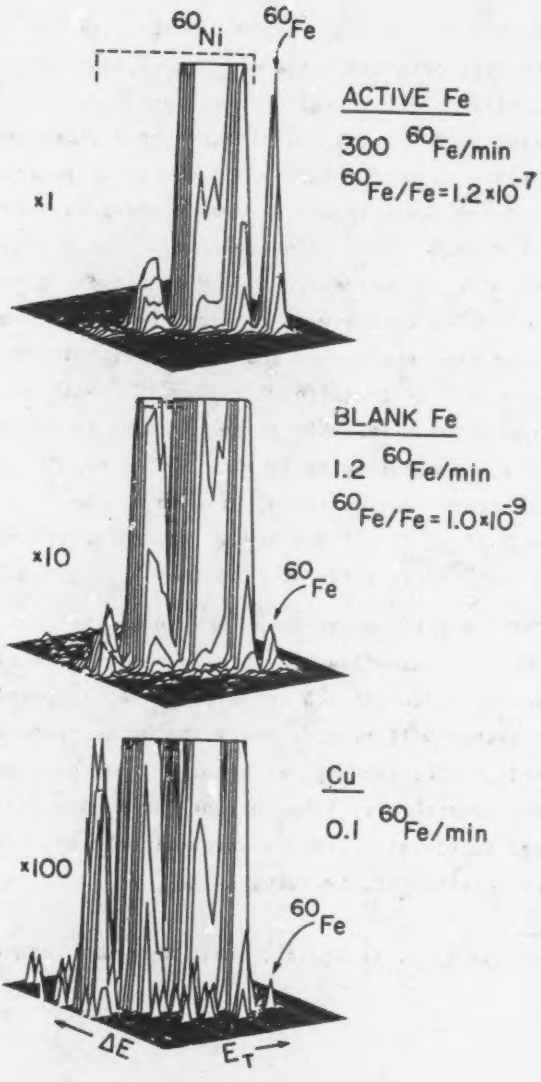

Fig. II-19. Isometric plot of energy loss, ΔE, vs. total energy signals, E_T, measured in the focal-plane detector of the split-pole spectrograph. All three dimensions are linear with the vertical scale varying as indicated.

sputter source.[4] The tandem-linac system accelerated the mass-60 ions to 360 MeV and these were detected using and Enge split-pole magnetic spectrograph. A strong ^{60}Ni background cmponent following ^{60}Fe through the entire acceleration process was separated by the difference in energy loss in a 2.8 mg/cm^2 thick Al foil stack. The subsequent position splitting in the focal plane of the spectrograph allowed a physical shielding of the main Ni component fromthe focal-plane detector. The resulting energy spectrum measured with an ionization-type detector is shown in Fig. II-19. The ^{60}Fe/Fe ratios were obtained by normalizing to the ^{56}Fe current measured at the entrance of the linac. From 18 individual runs on two active pellets, a ^{60}Fe/Fe ratio of 1.16×10^{-7} with an uncertainty of 20% was determined. The relatively large uncertainty is due to systematic errors in measuring an absolute ratio with such a highly complex system. At present we are measuring the (slow) grow-in of the ^{60}Co gamma-ray activity ($T_{1/2} = 5.27$ y, $E_\gamma = 1.332$ MeV). From preliminary values of this measurement and the ^{60}Fe/Fe ratio we find that $T_{1/2} \geq 4 \times 10^5$y.

The ^{60}Fe/Fe ratio measurement has shown that AMS experiments can be performed with the tandem-linac system in the mass-60 range. An extension to heavier radioisotopes seems possible, in particular when the completed ATLAS system will provide heavy-ion beams pproaching 1 GeV. Although combined accelerator systems become highly complex devices for quantitative mass spectrometry, the current trend of steadily increasing computer-assisted accelerator control may well make this type of measurement more feasible in the future.

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[4] J. L. Yntema and P. J. Billquist, Nucl. Instrum. Methods 199, 637 (1982)

E. SELECTED NUCLEAR SPECTROSCOPY AT THE TANDEM-LINAC

In addition to the programs described above, there are other activities at the tandem-linac. The main one involves on-line laser spectroscopy which has been initiated recently. The optical hyperfine structure of radioactive atoms will be studied, in order to extract information on spins, moments, and the variation of charge radii for ground states and isomers. The laser system has been installed and tests of the cryogenic helium jet which transports the atoms into the interaction region have been completed. Work is now proceeding on coupling the laser system to the cryogenic helium jet. There has also been a search for a transient electric field gradient acting on ions slowing down in a solid. Measurements have also been performed on the ${}^7Be(p,\gamma){}^8B$ reaction, which is of astrophysical interest, of resonances in ${}^7Be(\alpha,\gamma)$ and ${}^7Li(\alpha'\gamma)$ and of the ${}^7Be$ decay branching ratio.

a. Laser Spectroscopy of Radioactive Atoms (C. N. Davids, D. A. Lewis,* R. Evans,* M. A. Finn,† G. Greenlees,† and S. L. Kaufman†)

The linac target station for the cryogenic helium jet has been completed. Tests using the linac beam have been conducted, indicating copious production of Ba radionuclides using the ${}^{122}Sn({}^{12}C,xn){}^{134-x}Ba$ reactions. The skimmer efficiency for Ba is 2.5%, slightly higher than that obtained for lighter As, Ge, and Ga isotopes. This is expected since the opening cone angle at the capillary varies as $M^{-1/2}$, where M is the mass of the species. A large blower pump has been installed, and is expected to produce a better vacuum in the helium exhaust chamber. This in turn should lead to better cooling of the atomic beam upon emergence from the capillary.

The laser beam transport system between the laser laboratory and the cryogenic helium jet has been installed. Tests to reduce the laser light scattering background will begin soon.

Work with the stable atomic beam chamber has shown that the laser line width is 7 MHz. This is quite adequate for the isotope shift measurements. The light collection efficiency of the elliptical cylinder light collector has been measured using a line filament light bulb. It agrees with calculations, and should lead to a high overall efficiency for detecting bursts of photons emitted by the excited atoms.

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†University of Minnesota, Minneapolis, Minnesota.

A data-acquisition system consisting of an LSI-11/02 minicomputer, floppy disk drive, terminal, and CAMAC hardware has been assembled. This system enables spectra of burst multiplicity to be recorded. In addition, the computer controls the scanning of the dye-laser frequency in precise steps.

b. Search for Transient Electric Field Gradient Acting on Fast-Moving Ions in Solids (H. Ernst, W. Henning, T. J. Humanic, T. L. Khoo, S. C. Pieper, and J. P. Schiffer)

As a fast ion slows down in a solid the transient electric field acting on it should give rise to a field gradient at the nucleus. Such a field should interact with the quadrupole moment of the moving nucleus and cause a perturbation in the angular correlation of the emitted γ rays. If the gradient is sufficiently large it could be utilized as a powerful test for measuring the quadrupole moments of states with lifetimes as short as a few picoseconds. In our experiment we searched for a perturbation in the angular correlation of γ rays deexciting the 2^+ states of ^{56}Fe and ^{24}Mg, which were both Coulomb-excited in the bombardment of ^{24}Mg with 125-MeV ^{56}Fe beams from the linac. No effect was detected within experimental limits and an upper limit of 10^{21} V cm^{-2} was set for the electric field gradient. A paper has been published in Physical Review on the results.

c. The ^{7}Be(p,γ)^{8}B Reaction (B. Filippone,* A. J. Elwyn, C. N. Davids, D. Koetke,† and W. Ray, Jr.)

The ^{7}Be(p,γ)^{8}B reaction has been measured from E_{cm} = 117--1230 keV by detecting the delayed α particles from the ^{8}B β decay. The occurrence of this reaction in the sun produces high-energy neutrinos which account for nearly 80% of the neutrino capture rate in the ^{37}Cl solar neutrino experiment.

A ^{7}Be radioactive target ($t_{1/2}$ = 53.3 days) of 80 mCi was produced by a high-voltage electroplating technique in an organic solution. The ^{7}Be was produced via the ^{7}Li(p,n)^{7}Be reaction and then chemically separated from the ^{7}Li and purified.

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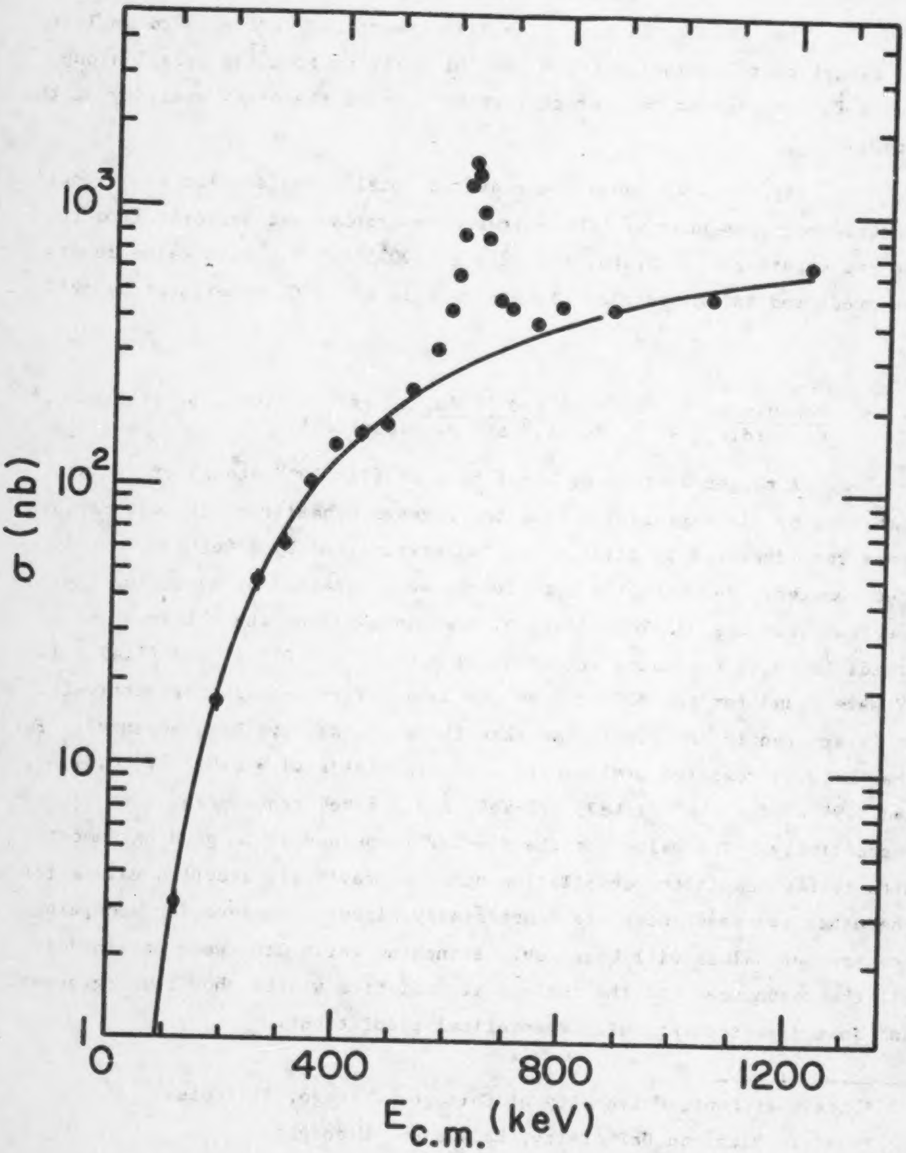

Fig. II-20. Total cross section for the reaction $^7Be(p,\gamma)^8B$ as a function of the center-of-mass energy. The solid curve is the cross section calculated from the theoretical s-factors of Ref. 1, normalized to the data.

[1] T.A. Tombrello, Nucl. Phys. 71, 459 (1965).

The $^7Li(d,p)^8Li$ and $^7Li(p,\gamma)^8Be$ reactions were used to analyze the target characteristics (from the ^7Li built up from ^7Be decay) along with a Pb- collimated NaI detector which scanned the γ-ray activity of the target.

Figure II-20 shows the measured total cross section as a function of center-of-mass energy. The extracted astrophysical S-factor from the present experiment is $S_{17}(0) = 0.0216 \pm 0.0025$ keV-b. This value lowers the predicted solar neutrino capture rate in the ^{37}Cl experiment by ~25%.

d. Resonances in $^7Be(\alpha,\gamma)$ and $^7Li(\alpha,\gamma)$ (A. J. Elwyn, B. Filippone,* G. Hardie,† R. E. Segel,‡ and M. Wiescher§)

A target containing about 80 m Ci (2×10^{16} atoms) of ^7Be was bombarded by alpha particles from the Argonne Dynamitron with the capture gamma rays detected by a large NaI(Tℓ) crystal and by a Ge(Li) spectrometer. The detector efficiences were obtained by measuring the spectrum from the 992-keV $^{22}Al(p,\gamma)$ resonance. From the thick-target yields $^7Be(\alpha,\gamma)$ resonance strengths $\omega\Gamma = (0.34 \pm 0.07)$ eV and (4.45 ± 1.2) eV were found for the 880-keV and the 1380-keV resonances, respectively. It is apparently the first time that these yields have been measured. For the $^7Li(\alpha,\gamma)$ reaction preliminary analysis yields $\omega\Gamma = 0.012$ eV, 0.54 eV, and 1.95 eV for the 401-keV, 820-keV, and 958-keV resonances, respectively. The value for the 820-keV resonance is in good agreement with that given in the compilation but the previously accepted values for the other two resonances are considerably higher. Reasons for accepting the present values will be given. Branching ratio data were obtained for all the resonances and the individual radiative widths show some agreement, and some disagreement, with theoretical predictions.

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§Ohio State University, Columbus, Ohio.

e. The ^{7}Be Decay Branching Radio (C. N. Davids, A. J. Elwyn, B. W. Filippone, S. B. Kaufman,* K. E. Rehm, and J. P. Schiffer)

The branching ratio for the electron capture decay of ^{7}Be to the first excited state in ^{7}Li is an important number in astrophysics. The currently accepted value for the branching ratio is 10.37 ± 0.12%, but a recent preprint by Rolfs et al. reports a value of 15.4 ± 0.8%. We have measured the branching ratio by implanting 89.04×10^6 ^{7}Be nuclei in a Si surface barrier detector and subsequently counting the 478-keV decay γ rays in a well-shielded Ge(Li) detector. The ^{7}Be nuclei were produced via the ^{1}H(^{7}Li,^{7}Be)n reaction at 15.5-MeV bombarding energy, and were allowed to recoil into an Enge split-pole spectrograph placed at 1.6° to the incident beam. A clean separation of ^{7}Be from contaminants allowed placement of the Si detector in the magnet focal plane, and an analysis of the energy spectrum in the detector yielded the total number of ^{7}Be nuclei. Figure II-21 shows the energy spectrum for one of the runs lasting about 40 minutes. The resulting branching ratio is 10.61 ± 0.23%, which agrees with the currently accepted value.

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*Chemistry Division, ANL.

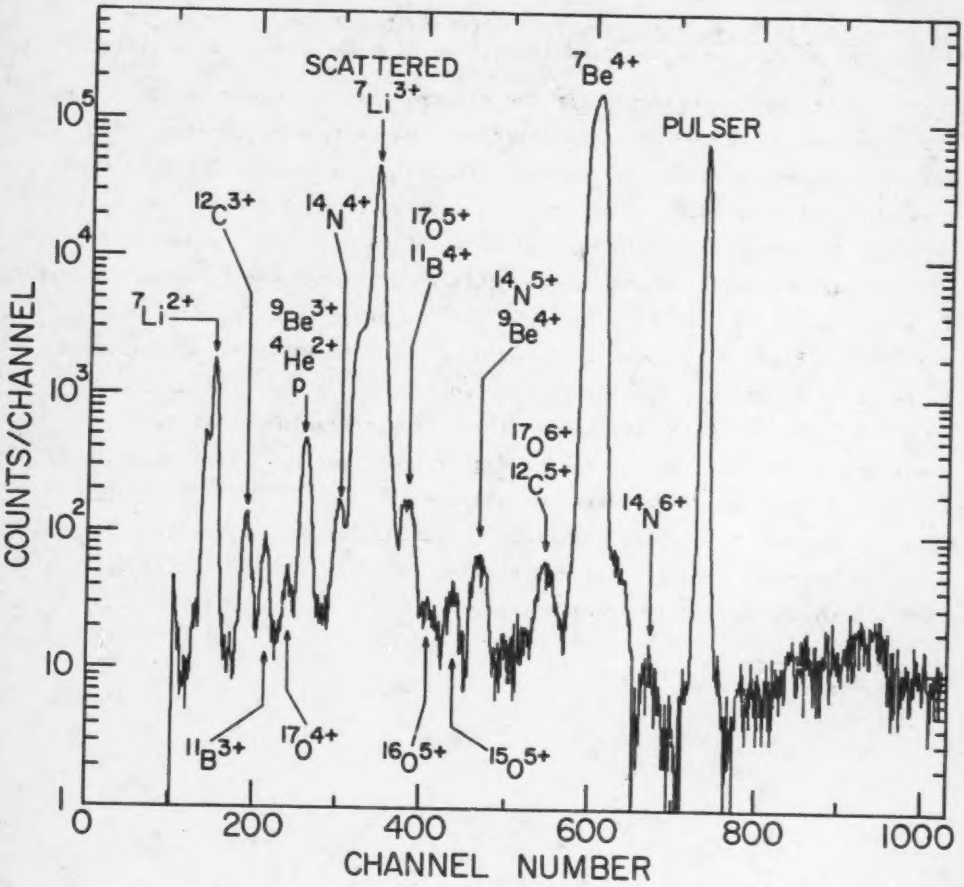

Fig. II-21. Energy spectrum in Si detector mounted in the focal plane of the Enge split-pole spectrograph. The double peak marked "$^7Li^{3+}$" is due to slit-edge scattered beam particles. Other identified peaks are due to ^7Li-induced reactions on ^7Li and ^{12}C.

F. EQUIPMENT DEVELOPMENT AT THE TANDEM-LINAC FACILITY

The experimental areas of the linac are now reaching completion. The Enge spectrograph is operational on a routine basis, and significant improvements have been made to its focal-plane detector. The 65" scattering chamber has been continually upgraded primarily to permit more refined operation with longer flight paths. Detectors have been developed for efficient detection of heavy evaporation residues and to permit high resolution time-of-flight measurements. A new beam line has been installed with two target stations. One has a thin-walled Al chamber for neutron time-of-flight measurements and the other incorporates an upgraded γ-ray facility. A plunger which fits inside the sum spectrometer has been extensively tested and used successfully in several experiments. A general-purpose beam line has been installed and used in several atomic physics experiments, while a beam line for a superconducting spectrometer is almost complete. Effort has also been devoted to planning for the ATLAS facility. This activity is described elsewhere in this document.

a. Ray-Tracing Corrections for the Focal-Plane Counter at the Spectrograph (K. E. Rehm)

Reactions between two medium-weight nuclei usually show a large kinematical shift. For experiments with the split-pole spectrograph this implies that the detector has to be moved very close towards the exit of the magnet, which is not possible for many cases due to mechanical reasons. It is, however, possible to reconstruct by ray-tracing techniques the actual focal plane from two position measurements taken outside the focal plane. From our measurements with two position wires, separated by 50 mm, we have obtained energy resolutions of $\sim 1 \times 10^{-3}$ after the ray-tracing correction. An example of the reconstruction of the actual focal plane is shown in Fig. II-22 for the case of elastic scattering of 50-MeV ^{16}O on ^{27}Al at $\theta_{lab} = 20°$. The same technique can also be used to correct the angle dependence of the ΔE signal. This strongly improves the Z resolution for heavy-ion reactions at large solid angles. Ray-tracing corrections are also of importance in future experiments with the split-pole spectrograph at the ATLAS accelerator. Presently we are working on the implementation of the ray-tracing correction into the on-line data-acquisition program.

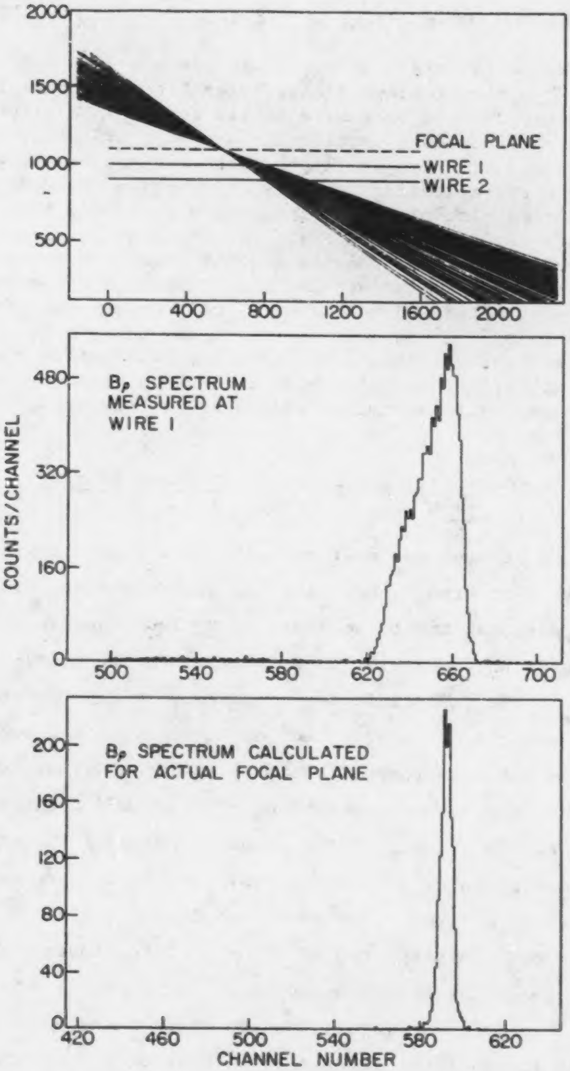

Fig. II-22. Reconstruction of the actual focal plane using two position measurements.

b. Test of the Large Focal-Plane Counter for the Linac Magnetic Spectrograph (K. E. Rehm, W. Kutschera, and D. G. Kovar)

Experiments with high-energetic (~10-MeV/nucleon) heavy ions in the magnetic spectrograph require large focal-plane detectors with good resolutions to identify the detected particles. We have thoroughly tested a 25-cm deep position-sensitive ionization chamber with ^{16}O, ^{37}Cl and ^{58}Ni ions. This detector is now used routinely for experiments at the linac spectrograph. Resolutions obtained with 150-MeV ^{16}O ions were: ΔE : 2.9%, E : 0.75%, position : 1 mm. The improvements in the ΔE and E resolution are mainly due to the use of CF_4 as counter gas, which has the additional advantage of being nonflammable. This allows us to study nuclear reactions between medium-weight nuclei on heavy targets with better resolution than hitherto possible. We are planning to add a parallel-plate avalanche counter to the present system for time-of-flight information to improve the mass resolution for experiments with projectiles in the A = 100 region.

c. A ΔE-E Detector for Fusion Measurements (W. S. Freeman, H. Ernst, D. F. Geesaman, W. Henning, W. Kühn, J. P. Schiffer, and B. Zeidman)

An improved ΔE-E detector has been constructed for identifying evaporation residues from heavy-ion fusion reactions. The detector consists of four silicon surface-barrier detectors (450 mm^2 × 300 μ thick) placed inside a ΔE gas-filled ionization chamber. The back plate on which the silicon detectors are mounted may be easily removed and replaced with another plate whose design and function is at the user's discretion. The maximum available gas volume of the ionization chamber is 19 mm height × 152 mm length × 60 mm deep, and provision is made for installing a grid to support thin windows ($\lesssim$100 $\mu g/cm^2$). The detector has been used successfully in conjunction with an electrostatic deflector to measure evaporation-residue angular distributions for several moderately heavy systems ($A_{CN} \sim 180$). In the course of these measurements, the limitations of the ΔE-E method for detecting and identifying very heavy, low-energy evaporation residues has become apparent. In the future we plan to incorporate time-of-flight measurements into the system as an additional means of identification.

d. Modifications to the 65" Scattering Chamber For Long Flight-Path Measurements (D. G. Kovar, R. Nielsen, and G. Rosner)

Modifications to the 65" scattering chamber have been made to allow for ≲1.5 meter flight paths for time-of-flight measurements. A new target position was installed at the entrance of the chamber with a collapsible movable arm attached to the new target position and an existing ring in the chamber. As the ring is rotated in the angular range 0° to 100° the new arm rotates from 0° to 55° and the flight path varies from ≲1.5 to 1 meter. A target holder with eleven target positions has been installed for measurements. This configuration has been used in measurements using two micro-channel detector systems plus a Si detector and masses of ≈55 amu have been resolved in studies of evaporation residues. Further modifications to allow for coincidence measurements using the new target position are planned.

e. The γ-ray Facility (P. Chowdhury, W. Evans, H. Emling,* R. V. F. Janssens, T. L. Khoo, and J. Worthington)

The γ-ray facility has been moved to another location in the new linac target area annex. As a consequence there is now more space around the target for large NaI detectors or for neutron time-of-flight measurements, thereby alleviating the congestion in the previous location. Improvements to the vacuum system and beam-diagnostics have also been made.

Extensive tests of a plunger for recoil-distance measurements have been conducted. The plunger incorporates several unique features, among them the support of the catcher foil on 3 independent push rods and the use of a microcomputer to control the rods. Tests have demonstrated that the position of the catcher foil as given by the microcomputer is accurate to within 1 µm. In addition, a new algorithm has been developed for quick remote adjustments to achieve parallelism between target and catcher foils. Measurements of state and feeding times as a function of γ-sum energy have been performed in ^{152,154}Dy, as described in sections A.c. and A.f. Future experiments will include similar measurements in ^{147}Gd, where we have identified yrast states to the highest spins known, in ^{186}Hg, and in some light Re isotopes. In the latter cases the core is soft toward deformation: lifetimes will provide important information on the deformation parameters and on their changes with spin.

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*GSI, Darmstadt, W. Germany.

Design studies are currently being undertaken for a facility consisting of (a) a sum-energy/multiplicity analyzer consisting of 60 bismuth germanate (BGO) detectors and (b) an array of 7 anti-Compton spectrometers, where BGO is used for detecting γ-rays which are Compton-scattered out of the Ge detector. The anti-Compton array will be arranged outside the sum-energy/multiplicity analyzer. Such a device will enable the nucleus to be probed to higher spins than has hitherto been possible with any existing detector systems. The sum energy/multiplicity filter will also provide valuable data in the study of reaction mechanisms.

f. Superconducting Solenoid Lens Electron Spectrometer (P. J. Daly,* Z. Grabowski,* W. Evans, R. V. F. Janssens, T. L. Khoo, and J. Worthington)

Work has continued for the construction of the Purdue superconducting electron spectrometer to be installed at the linac. The coils were delivered by the middle of the year. Field mappings were performed. They show that the original design goals are met and even exceeded. No particular problems were encountered in realizing the high magnetic fields.

Meanwhile, the beam-line design has been finalized at Argonne and construction has started. First studies of the beam quality through the line are expected in spring 1983. The installation of the spectrometer should take place before the end of the year. A variety of experiments is planned, some of which will take advantage of the possibility of measuring e^--e^- coincidences.

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*Purdue University, W. Lafayette, Indiana.

g. General-Purpose Beam Line

A general-purpose beam line has been constructed to which equipment may be attached for limited time intervals. Outside users or those with no facilities at the present permanent stations will be able to take advantage of this facility. It has already been used in several atomic physics experiments.

The target system for atomic physics experiments will include a scattering chamber for ion-atom and ion-foil collisions. Such a chamber (diameter 140 cm) would be attached to a high-resolution electron spectrometer, and also be used for Coulomb-explosion experiments involving charged-particle detection. A second target chamber further downbeam will be available for photon spectroscopy measurements of ion-atom and ion-foil collisions. Pumping systems will include two turbo-molecular pumps and an ion pump.

h. Nuclear Target Making and Development (G. E. Thomas)

The Physics Division has a facility which is used principally to produce very thin films for experiments at the Tandem-Linac and Dynamitron accelerators as well as for experiments of other members of the Division. In addition, it is available to any other division at the Laboratory needing this service and occasionally to other laboratories and universities.

This year we again produced targets varying in thickness from a few monolayers to several mg/cm^2. The different elements, isotopes, or compounds evaporated or rolled included the following: Au, Al, $\mathrm{BaF_2}$, $^{10,11,\mathrm{normal}}\mathrm{B}$, Bi, C, $^{40}\mathrm{Ca}$, $\mathrm{CH_2}$, $^{155,156}\mathrm{Gd}$, $^{76}\mathrm{Ge}$, K, $^{6,7,\mathrm{normal}}\mathrm{LiF}$, LiH, Li, $^{24,26,\mathrm{normal}}\mathrm{Mg}$, $\mathrm{MgF_2}$, $^{92,94,95}\mathrm{Mo}$, $^{58,62}\mathrm{Nc}$, $^{206,208,\mathrm{normal}}\mathrm{Pb}$, $^{96}\mathrm{Ru}$, $^{112,114,116,118,120,122,124}\mathrm{Sn}$, $^{28,29,30,\mathrm{normal}}\mathrm{Si}$, $^{125}\mathrm{Te}$, and $^{92,94}\mathrm{Zn}$.

Methods have been developed to better produce the more complex targets made for experiments at the heavy-ion facility. One such type is a "sandwich" produced by evaporating an absorber material (15 mg/cm^{-2}) onto a rolled separated isotope target (1 mg/cm^{-2}) or the target (1 mg/cm^{-2}) may be evaporated onto the rolled absorber material (15 mg/cm^{-2}). Another type is produced by evaporating the separated isotope (1 mg/cm^{-2}) onto a very tightly and smoothly stretched Au (1 mg/cm^{-2}) foil. "Sandwich" targets produced by the above methods include ^{155,156}Gd + Pb, ^{156}Gd + Bi + Pb, ^{92,94,95}Mo + Pb, ^{58,62}Ni + Pb, ^{122,124}Sn + Au, ^{125}Te + Pb, and ^{92,94}Zr + Pb.

New systems being developed for the facility include a computerized target-storage system using turbo-pumps (work in collaboration with J. N. Worthington and B. G. Nardi), a system for producing targets using a new type of sputter source, and a clean evaporator system using a cryo-pump. Plans for the future also include building a new type of multi-target evaporator system using a rotating wheel. A continuing objective is to improve target quality.

IV. THE SUPERCONDUCTING LINAC

R. Benaroya, J. M. Bogaty, L. M. Bollinger, R. C. Pardo,
K. W. Shepard, G. P. Zinkann, J. Aron,* B. E. Clifft,*
K. W. Johnson,* P. Markovich,* and J. M. Nixon

INTRODUCTION

The activities concerned with advancing the technology of the superconducting heavy-ion linac now have three major components. One is the specific task of completing and refining the prototype superconducting linac that functions as an energy booster for heavy ions from the tandem electrostatic accelerator. The second part consists of continuing investigations of various aspects of superconducting rf technology, some of which are of fairly general interest for accelerator technology. The third undertaking is the line-item project to extend the present tandem-linac accelerator into a substantially larger system called ATLAS.

All parts of the superconducting linac program are jointly supported by the Chemistry and Physics Division.

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*Chemistry Division, ANL.

A. PROTOTYPE HEAVY-ION SUPERCONDUCTING LINAC

This project, started in mid-1975 and now completed, has been concerned with the design, construction, installation, and testing of a small superconducting linear accelerator (linac) to serve as an energy booster for heavy-ion beams from the FN tandem accelerator. The principal objectives of the project have been to develop a new accelerator technology and to build the prototype for a heavy-ion energy booster that can be used to upgrade the performance of any tandem accelerator. The overall design is highly modular in character in order to provide maximum flexibility for future modifications and/or improvements. The last two resonators of the planned 24-resonator system were installed in 1982.

The booster linac is now complete in all respects. Its main features have been outlined in previous Annual Reviews. Some effort is still being devoted to perfecting various subsystems of the accelerator, as outlined in Sec. V, and this effort is resulting in a machine of excellent reliability. However, our developmental effort is now being devoted mainly to the ATLAS project.

By now, the booster has been used extensively (~10,000 hr) to provide beams for nuclear-physics research. This operational experience is summarized in Sec. V of this document.

The booster will continue to be used in its present form until late 1984 or early 1985, when it will be incorporated into the ATLAS facility.

B. INVESTIGATIONS OF SUPERCONDUCTING-LINAC TECHNOLOGY

This program includes several investigations of applications of superconducting technology to the acceleration of heavy ions. At the present time, the choice of work is guided principally by the urgent developmental needs of the heavy-ion booster and especially for ATLAS. Most of this work is included within the following topics: (a) superconducting accelerating structures, including studies of the phenomena that limit performance, (b) time-of-flight technology for pulsed beams, and (c) superconducting magnets for heavy-ion beams.

1. Superconducting Accelerating Structures

K. W. Shepard, G. P. Zinkann, and P. Markovich*

The development of superconducting accelerating structures for heavy-ion acceleration is proceeding on a broad front. This work includes (1) the development of the new class of resonator for use in ATLAS, (2) efforts to improve the performance of the two existing classes of resonators, and (3) the development of a new slow-tuner controller.

a. The ATLAS Resonator

For ATLAS it is desirable to have a resonator that is optimum for an ion velocity that is substantially higher than the present $\beta = 0.105$ unit. After a thorough design study, it was concluded that the best choice for our needs would be a split-ring resonator operating at 147.5 MHz (3/2 times the present frequency) in the same housing as the present $\beta = 0.105$ unit. This choice maximizes the acceleration of ions with $\beta = 0.16$. By optimizing the shape of all parts of the drift-tube assembly, it is expected that the accelerating field will be increased. This type of resonator and its older brothers are pictured in Fig. IV-1.

As was reported last year, a first prototype resonator was completed and partially tested in early 1982. Further tests showed that the unit had a good Q at low fields, but the maximum achievable accelerating field was limited to about 2 MV/m, less than half of the expected value. Although the test results were inconclusive, the data strongly suggested that at least two of the welds in the structure were defective. However, efforts to repair the welds were unsuccessful.

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*Chemistry Division, ANL.

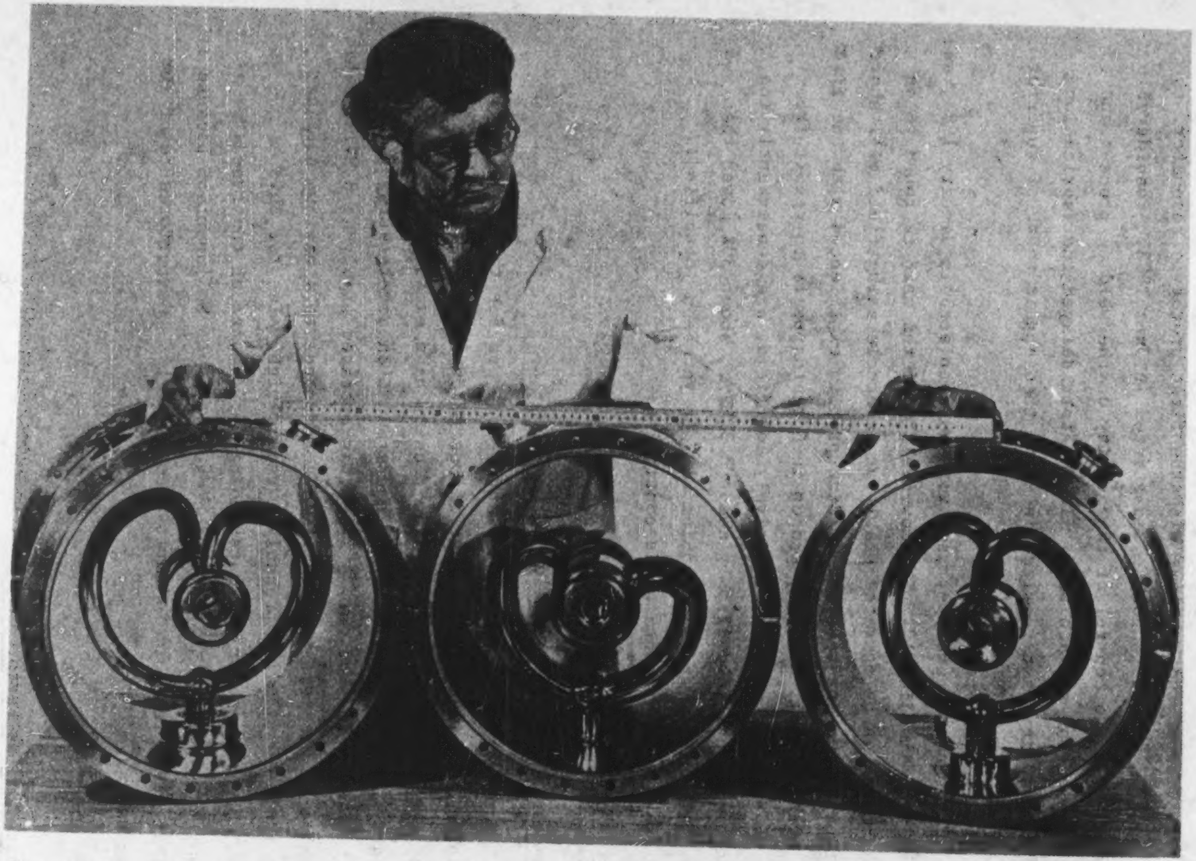

Fig. IV-1. The three classes of resonators to be used in ATLAS. On the left and right, respectively, are the proven β= 0.105 and β = 0.060 units that operate at 97 MHz. The new ATLAS unit, designed for β = 0.16 and 145.5 MHz, is in the middle. All three units have housings with an inside diameter of 16 inches.

In view of the problems with the first prototype resonator, the fabrication of a second prototype was started in June 1982. Considerable effort was devoted to control of the quality of the welding process and to an x-ray examination of each weld. This effort delayed the fabrication schedule but has at least resulted in welds that appear to be of superior quality.

The second prototype resonator was completed in January 1983, and testing started immediately. The low-field Q of the unit is found to be high. Also, it can be operated stably at an accelerating field well above 4 MV/m, thus indicating that the welding problem experienced with the first unit has been solved. However, a drop in Q that appears to result from electron loading sets in at a relatively low field, and consequently the useful accelerating field is only about 3.3 MV/m, about 30% lower than was expected. The cause for this problem has not yet been identified. Intensive work on the resonator is continuing.

b. Resonator Accelerating Field

During the past year the last resonators for the prototype linac were completed and installed. Most of our recent resonators are of excellent quality, but two of the low-β units have exceptional performance. The best of these was operated at an accelerating field of 6 MV/m with a power loss of only 4 W and was operated stably at 8 MV/m. This latter value of the accelerating field corresponds to a maximum surface electric field of 39 MV/m, probably a record high value for this quantity. The reason for the outstanding performance of the resonator is not known, but the result is nevertheless judged to be important because it proves that it is feasible to improve considerably the performance of our other resonators.

c. Restoration of Performance

During the past year, some of the resonators in the prototype linac had been in continuous use for more than three years, and the Q of some units had degraded so much that they were not useful. Previously, we had demonstrated that such units could be restored to their original performance by disassembly and electro-polishing, but this procedure is not entirely satisfactory because it is relatively time consuming. Consequently, we have tried the much simpler procedure of ultra-sonic cleaning and rinsing the surfaces with water and several organic solvents. It was found that this technique restores the performance of the unit almost completely, both with respect to Q and maximum accelerating field. This result is interesting not only because it establishes a simple method for restoring the performance of long-used resonators but also because it shows that the resonators do not suffer any fundamental degradation in some 10,000 hours of operation.

d. Slow-Tuner Controller

(K. W. Johnson,* B. E. Clifft, and K. W. Shepard)

After several unsuccessful attempts, a new type of slow-tuner pressure controller that meets all requirements has been developed and thoroughly tested. It is now in use on all of the resonators of the prototype linac and will be used in ATLAS. There have been no failures of the new system during the six months that it has been in use on the prototype linac.

2. Time-of-Flight Technology

R. C. Pardo, K. W. Johnson,* and B. E. Clifft*

The effort to develop time-of-flight technology as a major tool in the control and use of the prototype linac has continued. The main work during the last year has been the continuing effort to refine the energy-measurement system that makes use of the phase difference between two beam-excited resonators.

The validity of the concept involved in our energy-measurement system was demonstrated several years ago. However, it turned out that its electronic system was not able to respond properly to the confusion that results when a resonator in the linac goes momentarily out of lock, and consequently the energy-measurement system has not been much used. Now the electronic problems have been eliminated, however, and the beam energy can routinely be measured continuously and non-destructively with an accuracy of about two parts in 10^4. Unfortunately, this capability is available now only on the +19° beam line, which feeds the 60-in scattering chamber and the magnetic spectrograph. In time, the capability will be extended to the other beam lines.

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*Chemistry Division, ANL.

3. Superconducting Magnets

a. Prototype Bending Magnet

Work on the prototype superconducting magnet has proceeded vigorously during the past year. The coil has been rewound, the cryostat fabricated, machining of the iron completed, and the system assembled. Testing is expected to start in April 1983.

Although the magnet being developed is viewed as the prototype for several possible applications, it has design characteristics that are well matched to what is required of a beam-switching magnet in the ATLAS experimental area, and the prototype itself may end up in this application.

b. Heavy-Ion Beam Splitting

In the ATLAS system, we expect to split the beam into two components in the interface region between the present and the future linac sections. Two different kinds of magnets are being studied for this application: (1) a superconducting septum magnet and (2) a hybrid system consisting of an iron magnet with a field-free region produced by a superconducting super-tube. Both approaches appear to be attractive solutions to a difficult technical problem but both also involve some risk, since neither approach has been tried previously.

4. Near-Term Plans

Much of the effort in 1983 and 1984 will continue to be devoted to problems that are closely related to the refinement of the present linac and especially to the needs of ATLAS.

If necessary, work on the $\beta = 0.16$ resonator for ATLAS will be given a high priority. At this time, it is too early to know exactly what questions will be addressed, but if the experience with this new design is similar to that with earlier resonators, there will surely be some problems that need to be studied.

A related area that requires further work is the investigation of the factors that limit the performance of resonators. Now that we have three classes of resonators with somewhat different parameters, we expect to see performance patterns that will suggest models to be explored.

A considerable effort will be devoted to superconducting magnets during 1983 and 1984. In particular, the work will focus on the special magnets to be used for beam separation in the 40°-bend region of ATLAS. Since this area of work is little explored, it is likely to lead to new paths that are as yet unforeseen.

By late 1985, the ATLAS linac will be assembled and a sizable effort will need to be devoted to studying its characteristics. In particular, matching the beam from the present linac into the ATLAS linac may be time consuming initially and may require the development of new diagnostic techniques. In any case, the characteristics of the new kind of beam splitter will be thoroughly studied.

C. THE ATLAS PROJECT

The Argonne Tandem-Linac Accelerator System (ATLAS) is a heavy-ion accelerator being formed by enlarging the booster linac and by adding a large new target area, as shown in Fig. VI-2. The resulting system, consisting of the existing tandem and a 7-section linac, will have a performance that is approximately equivalent to that of a 50-MV tandem with two strippers.

ATLAS

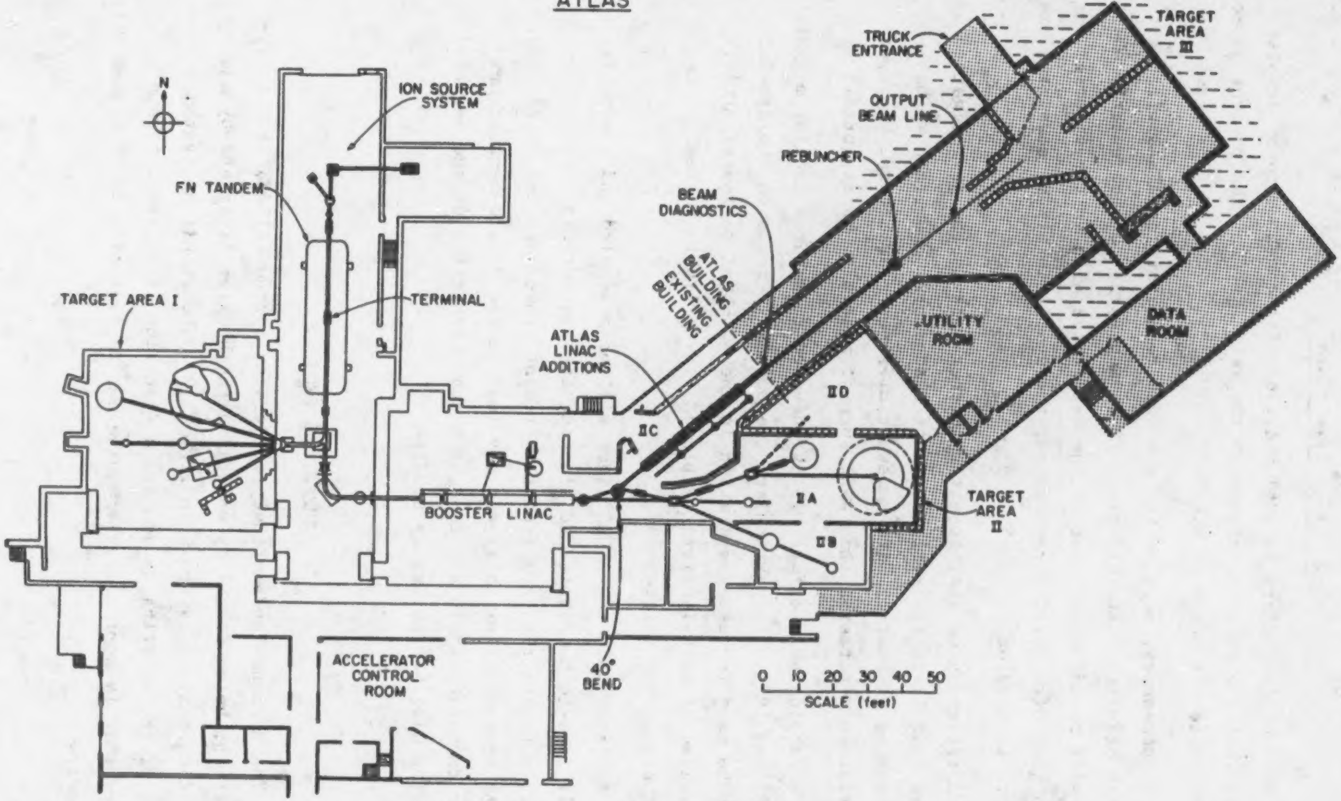
TRUCK ENTRANCE
TARGET AREA III
OUTPUT BEAM LINE
REBUNCHER
BEAM DIAGNOSTICS
ATLAS BUILDING
EXISTING BUILDING
ATLAS LINAC ADDITIONS
UTILITY ROOM
DATA ROOM
N
ION SOURCE SYSTEM
FN TANDEM
TERMINAL
TARGET AREA I
BOOSTER LINAC
II C
II D
II A
II B
TARGET AREA II
ACCELERATOR CONTROL ROOM
40° BEND
0 10 20 30 40 50
SCALE (feet)

Fig. IV-2. Layout of the ATLAS facility. The building areas shown in grey (dotted) and the accelerator components shown fully darkened are being added by the ATLAS project.

ATLAS is aimed squarely at the needs of precision nuclear-structure physics, providing beam energies up to 25 MeV/A, easy energy variability, and beams of exceptionally good quality. The short-pulse character of the beam will be emphasized so as to maximize its usefulness for time-of-flight and other timing measurements. An unusual feature of the facility is the capability of providing beams simultaneously for two independent experiments without a loss of intensity to either.

The ATLAS project was authorized in the FY 1982 budget at a level of $7.7 million, of which $4.0 million was appropriated in FY 1982, and the remainder in FY 1983. The project started officially in January 1982 when the initial funds were released. By the end of this reporting period (March 1983), the project was about 40% completed.

The construction of the ATLAS building addition got off to a very fast start and, because of economic conditions in the building industry, this has probably resulted in a considerable savings in cost. The first phase of construction, consisting of foundations and poured-concrete walls, was started in May 1982 and completed in October. The remaining work started in December 1982, and by the end of the present reporting period the building superstructure is in place, the enclosure of the building is nearing completion, and work on building services has started. We expect to start occupying the new building before Christmas 1983.

One of the main technical objectives of the ATLAS project is to add three linac sections that can effectively accelerate the relatively fast projectiles produced by the booster linac. This required the fabrication of 18 new resonators. Our present plan is to have the first 6 of these be of our proven $\beta = 0.105$ type in order to make it easy to match the beam from the booster into the new linac. The other 12 units will be of a new type that is optimum for ions with $\beta = 0.16$ and operates at an RF frequency of 145.5 MHz, 3/2 times the frequency of the booster units. The status of development of the new accelerating structure is summarized in section VI.B.1.a.

Because the accelerator addition involved in ATLAS is closely similar to the existing prototype linac, it was possible to start the work on major components as soon as funds were released. Consequently, rapid progress has been made. Cryostat fabrication is now largely completed, and one unit is expected to be ready for operation with installed resonators by late 1983.

Unlike the booster linac, we plan to start operation of the full ATLAS system only when all resonators are in place. Officially, this major milestone is scheduled for April 1985, but obviously we are trying to beat this schedule. In the meantime, the 24-resonator booster linac will continue to be intensively used for research in the present experimental area.

V. ACCELERATOR OPERATIONS

Introduction

This section is concerned with the operation of both the tandem-linac heavy-ion accelerator and the Dynamitron, two accelerators that are used for entirely different research. Developmental activities associated with the tandem and the Dynamitron are also treated here, but developmental activities associated with the superconducting linac are covered separately in Sec. IV, because this work is a program of technology development in its own right.

A. OPERATION OF THE TANDEM-LINAC ACCELERATOR

The tandem-linac accelerator is operated as a source of energetic heavy-ion projectiles for research in several areas of nuclear physics and occasionally in other areas of science. The accelerator system consists of a 9-MV tandem electrostatic accelerator and a superconducting-linac energy booster that can provide an additional 20 MV of acceleration. Figure V-1 shows the layout of this system, which will be operated in its present form until the end of 1984, when it will be incorporated into the larger ATLAS system. In both the present and future forms the accelerator is designed to provide the exceptional beam quality and overall versatility required for precision nuclear-structure research.

Some aspects of the technology of the superconducting linac are discussed in Sec. IV.

1. Operation of the Accelerator

The tandem-linac has been operated routinely and effectively during much of the past year as a research tool, mainly but not exclusively for nuclear physics. Some statistics about the operation are summarized in Table V-I, and representative beams that have been accelerated during the past year are described by Table V-II.

A notable feature of the use of beams from the accelerator is the increasing involvement of outside users, as indicated by the data of Table V-I. In particular, the running time allocated to outside users is expected to increase from 35% in FY 1982 to 51% in FY 1983.

The overall quality of the operation has improved greatly during the past year, partly because of the technical improvements summarized later and also because of a change in the way in which the linac is operated. In the first few years of operation, the beam user was responsible for the operation during all but the day-time shifts. This arrangement was necessary in order to minimize costs, but it was undesirable because it resulted in reduced running efficiency. The problem was largely eliminated in May 1982 when qualified operator/engineers were scheduled to be present during the evening shifts. This added manpower also made it possible to expand the running schedule from five to six twenty-four days per week, i.e., from Monday morning to Sunday morning.

Because of funding limitations in FY 1983, it has recently (February 1983) been necessary to reduce the running schedule back to a five-day week. Moreover, the accelerator will be shut down for at least six weeks in order to reduce operating costs. Since these reductions are in addition to the down times required for various accelerator-improvement activities (including ATLAS), the total running time in FY 1983 is expected to be considerably less than in FY 1982. This reduction is especially painful at this time because there is now an intense demand for running time and the superconducting linac is now an excellent research tool.

It is believed that it will be feasible to return to a six-day per week operating schedule in FY 1984.

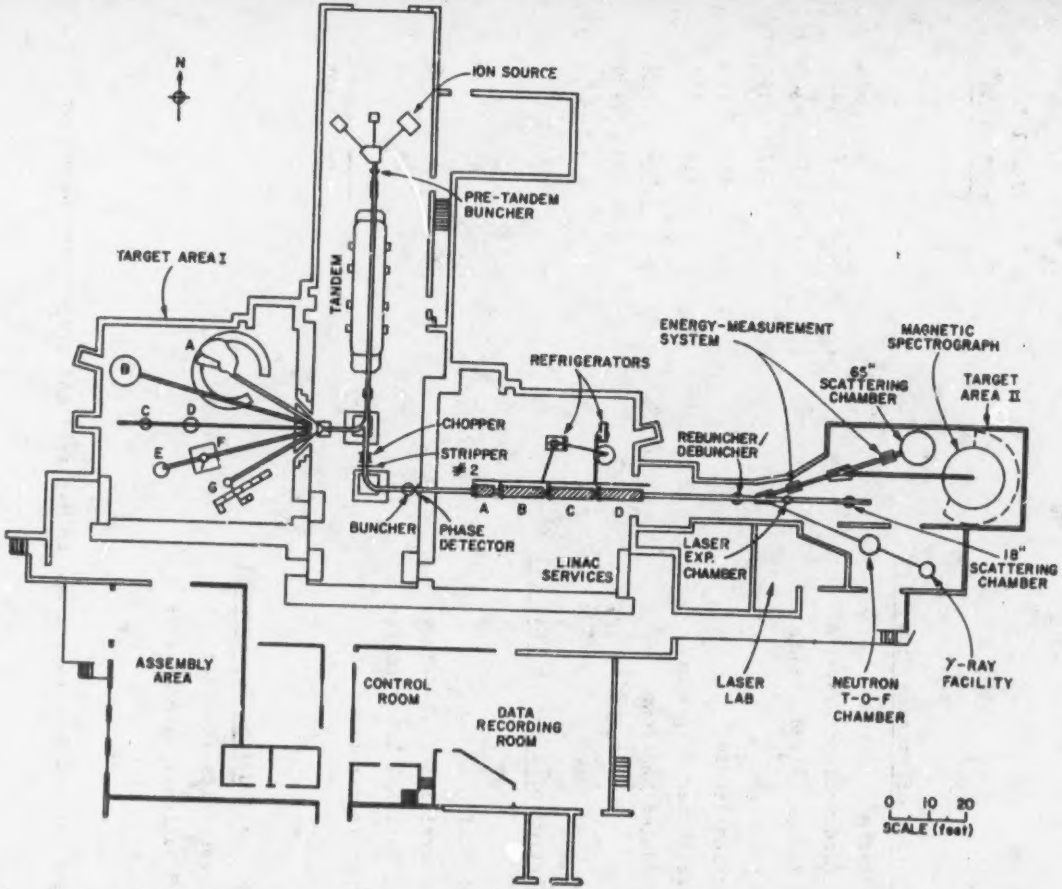
N
ION SOURCE
PRE-TANDEM BUNCHER
TANDEM
TARGET AREA I
A
B
C
D
E
F
G
CHOPPER
STRIPPER #2
BUNCHER
PHASE DETECTOR
A
B
C
D
REFRIGERATORS
LINAC SERVICES
ENERGY-MEASUREMENT SYSTEM
REBUNCHER/ DEBUNCHER
65" SCATTERING CHAMBER
MAGNETIC SPECTROGRAPH
TARGET AREA II
18" SCATTERING CHAMBER
LASER EXP. CHAMBER
LASER LAB
NEUTRON T-O-F CHAMBER
γ-RAY FACILITY
ASSEMBLY AREA
CONTROL ROOM
DATA RECORDING ROOM
0 10 20
SCALE (feet)

Fig. V-1. Layout of the present tandem-linac facility. The experimental apparatus shown on the figure is now all functional.

Table V-I. Operation of the ANL tandem-linac heavy-ion accelerator.

	Fiscal Year	
	1982	1983*
Distribution of Machine Time (hr)		
Research		
Tandem-Linac System	3,077	2,350
Tandem (stand alone)	437	180
Tuning	497	190
Machine Studies	397	600
Unscheduled Maintenance	714	450
Scheduled Shutdown	3,640	4,990
Total (1 yr)	8,760	8,760
Distribution of Research Time (%)		
ANL Staff	65	49
Universities (U.S.A.)	26	40
DOE National Laboratories	2	2
Other Institutions	7	9
Total	100	100
Outside Institutions Represented		
Universities (U.S.A.)	12	13
DOE National Laboratories	1	3
Other	7	8

*Data derived from experience to May 1983 and projection thereafter.

Table V-II. Representative beams accelerated by the ANL tandem-linac during the period 1 April 1982-31 March 1983. The quantities q_1 and q_2 are the ion charge states after the terminal stripper and the post-tandem stripper, respectively.

Particle	q_1	q_2	Tandem Energy (MeV)	Linac Energy (MeV)
^{12}C	5	5	51.0	107
^{16}O	6	8	59.5	171
^{17}O	6	8	59.5	152
^{19}F	7	9	68.0	196
^{24}Mg	7	10	68.0	212
^{28}Si	8	13	76.5	265
^{30}Si	7	12	68.0	214
^{32}S	9	14	85.0	242
^{34}S	8	13	76.5	266
^{35}Cl	8	13	76.5	197
^{37}Cl	9	14	85.0	268
^{40}Ca	9	14	85.0	252
^{48}Ti	9	15	85.0	324
^{58}Ni	10	19	93.5	410
^{60}Ni	10	19	93.5	327
^{64}Ni	10	19	93.5	389
^{82}Se	11	20	102.0	308

2. Status of the Superconducting Linac

The last two resonators of the prototype superconducting linac were installed and put into operation in October 1982, thus completing the 24-resonator system. When these resonators are operated at their maximum levels, the accelerating power of the combined tandem-linac system is roughly equivalent to that of a 24-MV tandem with two strippers for projectiles in the range $25 < A < 70$.

3. Linac Improvements

(J. Aron, R. Benaroya, J. Bogaty, L.M. Bollinger, B. E. Clifft, K. W. Johnson, P. Markovich, J. M. Nixon, R. C. Pardo, and K. W. Shepard)

The pace of development of the prototype linac continues to slow down as the various problems are solved and the emphasis is shifted to the ATLAS project. Nevertheless, significant improvements continue to be made.

a. Resonators

The final two resonators of the booster were completed and installed in the linac in October 1982.

b. Slow-Tuner Pressure Control

A slow-tuner pressure controller that satisfies all requirements has been developed and installed on all resonators. The excellent performance of this new system has eliminated one of the main operational problems of the linac.

c. Liquid-Nitrogen Distribution

A new liquid-nitrogen distribution system with vacuum-insulated lines and other refinements was installed in March 1982. Since then, there have been no failures of the LN system, which had previously been a frequent source of trouble and lost running time on the linac.

d. Helium Compressor

The third compressor for the model 2800 helium refrigerator has been installed. This compressor will be needed to cool the ATLAS linac.

e. Energy-Measurement System

The beam-energy measurement system that makes use of two beam-excited resonators has been considerably refined during the past year and is now used frequently to monitor the beam energy. Numerous electronic problems have been eliminated and the system can routinely and non-destructively measure the energy with an accuracy of a few parts in 10^4. The new system is now expected to be the primary source of information about beam energy for most experiments.

4. Upgrading of the Tandem

(P. K. Den Hartog, C. E. Heath, and F. H. Munson)

A large number of tasks are carried out annually with the objective of improving the performance and especially the reliability of the tandem. Many of these are difficult and time consuming but of little general interest. In this section, we mention only those that have the most important impact on the operation of the accelerator.

a. Computer Control and Monitoring of the Tandem

A program to monitor and eventually control the tandem with a computer has been started. This work is likely to extend over a period of years because of a shortage of funds and especially personnel to implement the plans. At the present time, the emphasis is on monitoring all important parameters of the machine. This work has already progressed far enough to be very useful for day-to-day operation. An example of this is the metering and recording of the tandem corona currents. Systematic information of this kind is expected to point to incipient mechanical and/or electrical problems.

All major subsystems of the accelerator will gradually be brought under computer control as time and funds permit. During the past year, a serial link between the terminal communication system and the computer-based tandem-monitoring system was put into operation. Also, the foil chamber in the terminal in now computer controlled.

b. West Injector

The control system for the new injector described in section I.E.c. has been designed and some components have been acquired. The control system will be installed in late FY 1983, after all exploratory tests of the injector have been completed.

c. Control of Tandem-Terminal Voltage

Now that we are routinely accelerating beams with rather complex mass spectra, the beam analyzer may lock on the wrong ion species when the accelerator system is recovering from a tandem spark. This problem has been largely eliminated by requiring the terminal voltage to return to its original value before voltage control is returned to the beam analyzer.

d. Focusing Lens in Terminal

Because of multiple scattering in the terminal stripping foil, the heaviest ions accelerated by the tandem have a relatively poor transmission. As part of the ATLAS project, an electrostatic quadrupole triplet is being installed in the terminal to refocus the beam and hence improve the transmission of the ion species of interest. This lens and its control system are now in place and the system is ready for testing.

e. Foil Stripping

The effort to improve the lifetime and quality of stripping foils is continuing. The primary effort at this time is to try to duplicate the results of the Japan Atomic Energy Institute, where a new fabrication procedure was reported to yield exceptionally long lifetimes. This work is being carried out in collaboration with S. Takeuchi, an exchange visitor from JAERI.

5. Ion-Source Development

(P. J. Billquist and J. L. Yntema)

This activity is aimed at developing improved negative-ion sources and specialized beams for use in the nuclear-physics program based on the superconducting linac.

a. Ion-Source Test Facility

The new test facility which was just coming into initial operation last year has been completed and extensively used to study several kinds of sources. An emittance-measurement device has been added to the system and is now in routine operation. The data provided by this device is essential for a complete evaluation of a source, since it indicates whether or not the output of the source can be efficiently transmitted through the tandem.

b. Inverted Sputter Source

The inverted sputter source with a new design, first described last year, has by now been extensively studied and used on-line to provide beams for the linac. Because of its high intensity, the source is able to produce acceptable beams of low-abundance isotopes from sputter targets of a number of natural elements. For example, in a recent nuclear-physics experiment the unusual beam ^{50}Ti was produced from natural titanium.

Experiments aimed at further enhancing the negative-ion yield of the inverted sputter source are in progress, and preliminary data suggest that substantial improvements may be feasible. Such an improvement would be important to our experimental programs, since many beams of interest are still too weak to be usable.

c. West Injector for the Tandem

A second ion-source position and injector for the tandem has been designed, installed, and tested. The system performs well and is used occasionally with the new source described in I.E.b. to provide special beams for the experimental programs. The remaining task is to install the electronics system required to control the ion source and injector in routine operation.

d. The SNICS Source

The SNICS source (the U. of Wisconsin design) has recently been modified to have internal optics that is similar to that in the ANL version of the inversted sputter source (described in section I.E.b.). Preliminary tests of the modified source suggest that it will have a somewhat greater heavy-ion yield than the inverted sputter source for some ions. If so, it will be very useful for some beams that are now too weak for the intended application.

e. Hydrogen Loading

For some ion-source target materials such as titanium, calcium, and zirconium, the negative-ion yield can be enhanced by loading the target with hydrogen. A loading chamber for this purpose has been built and put into service. A series of tests have been carried out to learn how to load targets reproducibly.

6. Near-Term Plans

a. Accelerator Operation

The level of funding in the President's Budget for FY 1984 will allow the operation of the tandem-linac system to return to a six-day-per-week schedule and it will also remove the need to shut down the operation for long periods of time in order to reduce costs. This longer and more regular schedule of operation will greatly increase running time.

Because of accelerator-improvement activities and the building activities connected with the ATLAS project, there will continue to be some interruptions in the accelerator operating schedule. However, these interruptions will be unimportant until late 1984.

Outside users are expected to play an increasingly prominent part in the research program at the superconducting linac. Consequently, we plan to install a formal program of outside-user assistance, as is discussed in Sec. V.7.

b. Linac Improvements

Most of the activities associated with the linac proper are now more in the nature of maintenance than improvements. However, upgrading of both the input and the output beam lines will continue to require effort. In particular, we need to tackle the general problem of computer control of beam lines, both because this capability is needed now and because experience now will be valuable for ATLAS.

c. Tandem Improvements

The main tasks through 1984 will be the following: (1) continue computer monitoring and control of the accelerator, (2) complete the West Injector, and (3) debug and refine the terminal lens. Completion of these three projects will enhance operational efficiency and accelerator capability to an important extent.

d. Ion Sources

There are two main elements to the near-terms plans for ion-source development. One is the refinement of the inverted sputter source and the SNICS (Wisconsin) source with the aim of improving efficiency and ease of operation. Both sources, in their present form, have good basic characteristics and are used to advantage to provide beams of interest to the experimental program. However, both also have operational defects that appear to have straightforward solutions. We will attempt to eliminate these defects during the next year.

The second task will be to design a new East Injector for use in ATLAS. One of the main objectives of the design will be to achieve better mass resolution than is provided by either of the present injectors.

7. Assistance to Outside Users of the Superconducting Linac

The tandem-linac accelerator and its associated experimental apparatus form a complex system that requires users to master a mass of technical matters. Consequently, outside users need guidance and assistance in order to work effectively. Until now, this assistance has been informal. We propose to start a formal assistance program in FY 1984 by providing a wider range of assistance by a designated group of individuals with continuing responsibilities.

Outside use of the superconducting linac has continued to increase, both with respect to the number of persons involved and the total amount of running time provided. In particular, the fraction of running time allocated to outside users has increased from 35% in FY 1982 to 51% in FY 1983.

The severely restricted funding level for FY 1983 in the heavy-ion program requires that the total running time for FY 1983 be reduced substantially below the FY 1982 level. This reduction, combined with the increase in the number of outside users, is making it difficult to accommodate all users under the present time-allocation policy, in which all users are allocated time on a uniform basis. Consequently, we now believe that the time has come to modify the policy, and this issue will be presented for discussion at the next (second) meeting of the Policy Advisory Committee. The first meeting of this committee was held in June 1982, at which time the committee recommended that our present informal system of running-time allocation should be maintained as long as it continued to work well.

The increased support for heavy-ion research in the President's Budget for FY 1984 will permit the superconducting linac to be operated much more intensively than in FY 1983, resulting in a substantial increase in the availability of running time for outside users. Moreover, the increasing degree of completeness of the experimental apparatus and continuing refinements of the accelerator will make the facility a very attractive one for research in precision heavy-ion research. Consequently, by FY 1984, outside use of the superconducting linac will be a major component in the national program for heavy-ion research, and this level of effort requires that we start to implement a formal user-assistance program.

Our present plan is to provide the following assistance for outside users: (1) general liaison services, (2) instruction on the characteristics of the accelerator system as a whole, (3) help in planning experiments, particularly with regard to compatibility between the user's equipment and the accelerator facility, (4) instructions on the use of particular major apparatus that is part of the ATLAS facility, (5) instruction and help with the use of computer hardware and software, (6) a well-defined mechanism for making use of ANL facilities to solve unforeseen technical problems, (7) some technical support in setting up experiments, (8) office space, and (9) a minimal level of typing service.

The magnitude of the outside use of the accelerator during the past year may be judged from the following two lists: (1) the experiments performed by outside users and (2) the institutions represented. As may be seen from the names associated with each experiment, the university groups are by now playing a major role in an important fraction of the experiments and a dominant role in some.

a. Experiments Involving Outside Users

All experiments in which outside users participated during the period April 1982 to January 1983 are listed below. The names in parentheses are Argonne collaborators.

(1) Development of a Laser-Spectroscopy Experimental Program
M. A. Finn, G. W. Greenlees, and S. L. Kaufman, Univ. of Minnesota; R. M. Evans and D. A. Lewis, Iowa State Univ. (C. Davids)

(2) Spectroscopy of ^{100}Cd
L. Cleemann, C. Maguire, W. C. Ma, D. Cacic, and M. Barclay, Vanderbilt Univ. (T. L. Khoo, R. Janssens, D. Frekers, and P. Chowdhury)

(3) Measurement of K-Vacancy Equilibration Lengths in Solids
P. Cooney, Millersville State College (E. Kanter, D. Schneider, and B. Zabransky)

(4) Measurements of Nuclear States of ^{152}Yb
Y.-H. Chung, P. J. Daly, Z. Grabowski, J. McNeill, and M. O. Kortelahti, Purdue Univ. (R. Janssens, P. Chowdhury, and T. L. Khoo)

(5) Time-of-Flight Measurements of Evaporation Residues Produced in the ^{16}O + ^{24}Mg Reaction
J. J. Kolata, J. D. Hinnefeld, R. J. Thornburg, and R. J. Vojtech, Univ. of Notre Dame; F. W. Prosser, Jr., University of Kansas (D. Kovar, T. Humanic, R. R. Betts, P. Chowdhury, D. J. Henderson, R. Janssens, W. Kühn, G. Rosner and K. Wolf)

(6) Accelerator Mass Spectroscopy of ^{44}Ti
B. Stievano, INFN, Legnaro (D. Frekers, W. Henning, W. Kutschera, K. E. Rehm, R. Smither, and J. Yntema).

(7) ^{37}Cl Induced Fusion
F. W. Prosser, Jr., Univ. of Kansas (W. Freeman, W. Henning, D. Frekers, D. Geesaman, J. P. Schiffer, and B. Zeidman)

(8) Direct Reactions on ^{208}Pb
M. Paul, Hebrew Univ., Jerusalem (K. E. Rehm, and W. Kutschera)

(9) Detection of High-Rydberg Atoms
Z. Vager, Weizmann Institute (D. Gemmell, E. Kanter, and D. Schneider).

(10) Accelerator Mass Spectroscopy of ^{41}Ca
M. Paul, Hebrew Univ.; X. Ma, Institute of Atomic Energy, Peking (W. Kutschera, D. Frekers, K. E. Rehm, R. Smither, and J. Yntema)

(11) Investigation of ^{186}Hg Isomeric State
P. J. Daly, Z. Grabowski, Y.-H. Chung, J. McNeill, M. O. Kortelahti, Purdue Univ. (R. Janssens, D. Frekers, P. Chowdhury, and T. L. Khoo)

(12) Shape Change in ^{155}Er
G. Bastin, C. Schuck, CNRS, Orsay; F. Beck, CNRS, Strasbourg; M. O. Kortelahti, Purdue Univ. (R. Janssens, T. L. Khoo, W. Kühn, and D. Frekers)

(13) Lifetime Measurements on the $^{158}Er*$ System
H. Emling, GSI, Darmstadt; R. J. Broda, Y-H Chung, P. J. Daly, Z. W. Grabowski, M. O. Kortelahti, J. McNeill, Purdue Univ. (P. Chowdhury, W. Kühn, T. L. Khoo, R. Janssens, and G. Rosner)

(14) Inelastic and Single-Nucleon Transfer for ^{16}O on ^{40}Ca
J. J. Kolata, R. J. Vojtech, Univ. of Notre Dame (D. Kovar, R. Pardo, K. E. Rehm, G. Rosner, and H. Ikezoe)

(15) Fusion with ^{40}Ca Beams
H. A. Al-Juwair, R. J. Ledoux, M.I.T. (R. R. Betts, and S. Saini)

(16) Fission and Fast Fission for the Systems ^{19}F, ^{24}Mg, ^{28}Si and ^{208}Pb
C.-K. Gelbke, B. Tsang, W. G. Lynch, H. Utsunomiya, Michigan State Univ.; P. A. Baisden, M. A. McMahan, Lawrence Livermore Laboratory (B. Back and S. Saini)

(17) Very High Spin States in ^{147}Gd
J. Borggreen, G. Sletten, Niels Bohr Institute; R. J. Broda, Y.-H. Chung, P. J. Daly, Z. W. Grabowski, M. O. Kortelahti, and J. McNeill, Purdue Univ. (P. Chowdhury, R. Janssens, T. L. Khoo, D. Frekers, and W. Kühn)

(18) Isomers in N = 82 Nuclei
R. J. Broda, Y-H Chung, P. J. Daly, Z. W. Grabowski, M. O. Kortelahti, and J. McNeill, Purdue Univ. (T. L. Khoo, R. Janssens, and P. Chowdhury)

(19) Two Electron Titanium Wavelengths
A. E. Livingston, Univ. of Notre Dame (H. G. Berry, J. Hardis, and W. Ray)

(20) Structure of Hg Isotopes
R. J. Broda, Y-H Chung, P. J. Daly, M. O. Kortelahti, Z. Grabowski, and J. McNeill; (R. Janssens, T. L. Khoo, and D. Frekers)

b. Outside Users and Institutional Affiliations

(1) Michigan State University
- D. A. Ardouin
- C.-K. Gelbke
- W. G. Lynch
- B. Tsang
- H. Utsunomiya
- Z. Xu

(2) Purdue University
- R. J. Broda
- Y.-H. Chung
- P. J. Daly
- Z. W. Grabowski
- M. O. Kortelahti
- J. McNeill

(3) Notre Dame University
- J. D. Hinnefeld
- J. J. Kolata
- A. E. Livingston
- R. J. Thornburg
- R. J. Vojtech

(4) Vanderbilt University
- M. Barclay
- D. Cacic
- L. Cleemann
- W. C. Ma
- C. Maguire

(5) Iowa State University
- R. M. Evans
- D. A. Lewis

(6) University of Kansas
- F. W. Prosser, Jr.

(7) Lawrence Livermore Laboratory
- P. A. Baisden
- M. A. McMahan

(8) M.I.T.
- H. A. Al-Juwair
- R. J. Ledoux

(9) University of Minnesota
- M. A. Finn
- G. W. Greenlees
- S. L. Kaufman

(10) Millersville State College
- P. Cooney

(11) U. S. Naval Academy
T. Humanic

(12) CNRS, Orsay
G. A. Bastin
C. Schuck

(13) CNRS, Strasbourg
F. Beck

(14) University of Copenhagen
J. Borggreen
G. Sletten
S. Bjørnholm

(15) G.S.I., Darmstadt
H. Emling

(16) Hebrew University, Jerusalem
M. Paul

(17) INFN, Legnaro (Italy)
B. Stievano

(18) Weizmann Institute
Z. Vager

(19) Institute of Atomic Energy, Peking, P.R.C.
X. Ma

c. Summaries of Major User Programs

Several groups listed in the above tables have embarked on extensive research programs that are likely to make use of the tandem-linac accelerator for several years. In order to give some indication of the extent of these efforts, the following descriptions summarize the research of five groups that have been most active during the period April 1982 to March 1983.

i. The Purdue University Group (P. J. Daly, Z. Grabowski, Y. H. Chung, S. R. Faber, H. Helppi, M. Kortelahti, A. Pakkanen, J. McNeill, and J. Wilson)

The Purdue University group has an active program on high-spin nuclear states at the linac. The personnel currently includes two professors, one visiting scientist from Poland, one post-doc, and three graduate students. One student whose thesis was largely based on work conducted at the linac has already graduated. A second student, whose work was entirely based on linac experiments, will soon complete his thesis.

Our program uses in-beam γ-ray techniques and is directed at several aspects of nuclear structure at high spin. We are testing the validity at the $Z = 64$ sub-shell closure through spectroscopic studies of $N = 82$ nuclei close to the proton drip line. This past year a 40-μs 10^+ isomer was discovered in $^{152}_{70}$Yb$_{82}$ which, having a half-filled proton $h_{11/2}$ shell, was predicted to have a long-lived isomer. By studies on $N = 87$ and 88 Dy isotopes we are also investigating the transition between oblate aligned-particle and prolate-collective structures as a function of both spin and neutron number. Evidence for a prolate-to-oblate shape change has been found in ^{153,154}Dy. Studies in ^{186}Hg have revealed for the first time decoupled $\nu i_{13/2}$ bands with both prolate and oblate shapes.

The program is conducted in close collaboration with the γ-ray group at Argonne and details may be found elsewhere in this document.

We have begun a project to construct a superconducting solenoid lens to be used as a conversion-electron spectrometer. The solenoid has been delivered by the manufacturer and the magnetic field profile has been determined to be within specifications. The spectrometer is currently being assembled at Purdue and, after testing there, will be installed at Argonne late in 1983. A lens spectrometer, on loan from the University of North Carolina and Oak Ridge National Laboratory, has been prepared for on-line use in the interim period.

ii. University of Kansas Collaboration (F. W. Prosser, Jr.)

Heavy-ion reaction mechanisms are being studied by observing the partition of reaction cross section and its dependence on energy and neutron excess. Fusion-fission, fusion-evaporation, and deep inelastic scattering for ^{32}S projectiles incident on targets of ^{112,116,120,124}Sn were studied over the energy range 130-247 MeV. In a search for entrance-channel effects in the formation of compound systems, the even-A Sn isotopes $^{112-114}$Sn were bombarded with beams of ^{58}Ni and ^{64}Ni at laboratory energies that varied from 230 to 322 MeV. In these measurements, the influence of neutron excess (for both target and projectile) upon the fusion-evaporation yields was emphasized.

In addition, the energy dependence of fusion and incomplete fusion processes for lighter systems involving ^{28}Si have been studied. In a search for incomplete momentum transfer (i.e., incomplete fusion), velocity spectra were measured for individually-resolved evaporation-residue masses produced in reactions of ^{28}Si projectiles at $E_{lab} \gtrsim 260$ MeV on targets of ^{12}C, ^{24}Mg, ^{24}Al, ^{28}Si, and ^{40}Ca. Also, in order to investigate the role of entrance-channel effects, evaporation-residue cross sections were measured for the reactions ^{28}Si + ^{28}Si and ^{16}O + ^{40}Ca, which form the same compound nucleus ^{56}Ni. The ^{28}Si + ^{28}Si system displays significantly smaller cross sections at higher energies than does ^{16}O + ^{40}Ca. Further investigations of this effect are planned.

iii. MSU and LLL Collaboration (C. K. Gelbke, W. Lynch, M. S. Tsang, Z-Xu, P. Baisden and M. McMahan)

The properties of fission fragments from the ^{32}S + ^{208}Pb reaction have been studied in detail. These studies include measurements of cross sections, angular distributions, fragment masses, and folding-angle distributions at projectile energies of 180-270 MeV. This study shows that compound-nucleus formation is strongly suppressed for this reaction system even at the lowest bombarding energies, with a major fraction of the cross section going to the quasi-fission reaction. In a subsequent experiment, which is presently being analyzed, we have measured angular distributions for ^{19}F, ^{24}Mg, ^{28}Si + ^{208}Pb reactions over a range of beam energies in an attempt to localize the onset of quasifission, which is known to be absent in the ^{16}O + ^{208}Pb reaction and dominating in the ^{32}S + ^{208}Pb reaction.

In the next experiment we plan to measure the neutron emission from the ^{32}S and ^{208}Pb reaction with the aim of determining the ratio of pre- to post-fission neutrons. It is anticipated that such measurements will be helpful in determining the time scale of the quasifission reaction, a quantity which is of central importance for the development of a better understanding of heavy-ion reaction dynamics involving large mass transfers.

iv. Iowa State and Minnesota Collaboration (D. A. Lewis, R. M. Evans, G. W. Greenlees, and S. L. Kaufman and M. A. Finn)

This project will use on-line laser spectroscopy to study the optical hyperfine structure of radioactive atoms. The objective is to extract information on spins, moments, and the variation of charge radii for ground states and isomers. The species under investigation will be produced by heavy-ion beams fromthe tandem-linac. The radioactive atoms recoil from the production target, become thermalized in a helium atmosphere, and then are transported by a liquid-nitrogen-cooled helium jet to the laser interaction region. Resonance fluorescence spectroscopy will be employed to observe the optical transitions. Essentially Doppler-free linewidths will be obtained by collimating the atoms into an atomic beam as they emerge from the helium jet. Two cooled photomultiplier tubes will detect the fluorescent light.

The linac target station for the cryogenic helium jet has been completed. Tests using the linac beam have been conducted, indicating copious production of the Ba radionuclides using the $^{122}Sn(^{12}C,xn)^{134-x}Ba$ reactions. The skimmer efficiency for Ba is 2.5%, slightly higher than that obtained for lighter As, Ge, and Ga isotopes. A large blower pump has been installed, which should lead to better cooling of the atomic beam upon emergency from the capillary. The laser beam transport system between the laser laboratory and the cryogenic helium jet has been installed. Tests to reduce the background of scattered laser light will begin soon. It is probable that measurements with a complete system will begin in the summer of 1983.

v. University of Notre Dame (J. Kolata, J. Hinnefeld and R. Vojtech)

We have participated in studies of the energy dependence of fusion and incomplete fusion cross sections for reactions induced by ^{16}O and ^{28}Si projectiles. Velocity spectra of individually-resolved evaporation-residue masses produced in $^{16}O + ^{12}C$, ^{24}Mg, and ^{40}Ca reactions at $E_{lab}(^{16}O) < 150$ MeV and $^{28}Si + ^{12}C$, ^{24}Mg, ^{27}Al, ^{28}Si, and ^{40}Ca reactions at $E_{lab}(^{28}Si) < 260$ MeV were measured by means of time-of-flight techniques, and the results were compared with theoretical predictions for complete fusion. Evidence for incomplete momentum transfer (i.e., contributions from incomplete fusion) was observed at the higher bombarding energies for some systems, but not for others. Further investigations of this projectile-target dependence are planned. As a part of a study of the energy dependence of reactions induced by a variety of projectiles on ^{40}Ca and ^{208}Pb, the cross sections for elastic and inelastic scattering and for transfer reactions were measured for the ^{16}O + ^{40}Ca system at $E_{lab}(^{16}O)$ = 150 MeV. The angular distributions will be compared to the predictions of DWBA and CCBA to test the adequacy of the calculations at the higher bombarding energies.

VI. DATA ACQUISITION AND ANALYSIS SYSTEMS

A. ON-LINE

The construction of a new accelerator (ATLAS) has provided the opportunity to examine critically the future needs of the Division with respect to data acquisition and has led to the conclusion that the present system based on PDP 11/45's with the operating system DOS could not fulfill the anticipated needs. Hence, for the moment, the present on-line data-acquisition systems are being only maintained and no extensive development effort is planned for them.

B. OFF-LINE

The VAX 11/780 is proving to be very useful for analysis and is being used for an ever-increasing variety of purposes. To enhance its capability a 6250 bpi, 125 ips magnetic tape unit was ordered (and as of this writing, installed); an additional 1.5 Mb of memory was likewise installed thus bringing the total memory to 5 Mb; and lastly, a floating-point accelerator has been ordered and received but not yet installed.

C. FUTURE

A project has been initialized to provide for the data-acquisition systems needs for the future. The project (called DAPHNE, for Data-Acquisition by Parallel Histogramming and NEtworking) involves parallel processors to histogram buffers of events before passing them to the main acquisition computer. The project is now into its planning phase and feasibility studies are being performed.

2.0 Brookhaven National Laboratory Double MP Tandem Facility

1. **What new science is being explored by this facility? What scientific opportunities are being exploited?**

   Answer: In the area of nuclear structure, the unique capabilities of an MP Tandem accelerator are being utilized to explore numerous aspects of nuclear structure such as the behavior of nuclei at very high spin. Technical advances in accelerator performance (higher voltage, more species of beams, including radioactive ones, etc.) are continually being exploited.

   In the near future, tandem injection of heavy ions into the AGS will provide beams of heavy ions up to mass 32 at center of mass energies about four times greater than those currently available (the Berkeley Bevalac). This increased energy will open a region of the nuclear matter phase diagram not accessible previously for relativistic heavy ion research. Most exciting of the new possibilities is the exploration of nuclear matter at densities about six times normal nuclear matter and at temperatures of about 140 MeV.

   It is at this density and temperature (similar perhaps to the conditions that prevail in neutron stars) that the quarks which are normally confined to a single nucleon volume are expected to become deconfined and aggregate into larger containment volumes.

   It is not anticipated that the signatures for the formation of the quark-gluon plasma will be simple to find. Consequently, a detailed understanding of the reactions that take place at these new heavy ion energies will be necessary to trace out the equation of state of nuclear matter. Experiments must be made with different beam projectiles and different targets; reaction products of many types must be observed. Nonetheless, the expectation for new discovery is universal. The scientific staff is redirecting its research interests to prepare experiments in this new field of physics.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

   Answer: MP-7 has been upgraded from its original warrantied voltage of 10 MV to 16MV and, when coupled to MP-6 in the 3-stage mode, operates equivalent to a single, 2-stage tandem at 19 MV. The MP tandem in Strasbourg, France has recently been upgraded to 18 MV performance by the addition of a new kind of intershield, called a "portico", which they invented. A similar portico will soon be installed in the BNL MP-7 machine which should then allow voltages up to 18 MV and 3-stage performance equivalent to a single 21 MV tandem. With this portico addition the BNL tandem facility will only be surpassed by two operating machines in the world; at the Oak Ridge National Laboratory and at Daresbury, England, where each machine is approximately twice the size of an MP and will operate in the 20-25 MV region. Although other types of accelerators produce heavy ion beams of higher energies, the variety of beam species up to mass 238 and including beams of rare and radioactive isotopes (^{14}C), the high beam quality, and ease of energy and species change are excellent.

One of the MP accelerators, MP-1 at Yale, is being upgraded to a much larger size machine called an STU and rated at 20 MV operation. With the addition of a portico, it is expected to attain voltages as high as 22 MV. A completely new design of electrostatic machine called a "Vivitron" is planned for construction in Strasbourg and they expect it to operate up to 35 MV.

The dual tandem facility at BNL also allows operation in a four-stage deceleration mode that is unique in the world in its capability. In this case, the second machine, MP-7, operating with negative voltage, accelerates positive heavy ions, injected from the first machine, to very high energies up to the high voltage terminal where they are then completely or nearly completely stripped of electrons and decelerated to very low energies suitable for atomic physics measurements. The present record low energy, totally stripped ions, are 2.5 MeV $^{37}Cl^{17+}$ ions which have been used by scientists from many parts of the world to study combined atom X-rays with completely new and unique results.

Finally, the injector accelerator, MP-6, provides the highest energy negative ion beams in the world, permitting unique studies of atomic and molecular physics.

The development of a pulsed high current negative ion source at BNL, from a commercially available source has allowed the demonstration of pulsed heavy ion beams from MP-7 approximately 100 times more intense than produced by any other tandem accelerator in the world. These pulsed beam currents are comparable to those produced by the two most powerful heavy ion linacs in the world, the HILAC at Berkeley and the GSI machine in Germany. High current pulsed beam tests with MP-7 operating at 15 MV produced 45 particle microamps of $^{16}O^{6+}$ ions and 27 particle microamperes of $^{32}S^{9+}$ ions with 10, 220 microsecond-long pulses per second.

These pulsed heavy ion beams also have approximately 100 times smaller emittance than those from the large linacs which means that a comparably larger number of turns can be injected into any synchrotron. This high current source, as well as others under development, may produce even more intense beams in the future.

3. **What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?**

Answer:

1. A unique, large volume, cosmic-ray-suppressed NaI crystal for detection of 10-100 MeV gamma rays with high resolution.
2. A QDDD magnetic spectrometer for high energy, high-Z, and high mass resolution heavy ion reaction measurements. The spectrometer features a state of the art focal plane detector.
3. A recoil mass spectrometer in the form of a velocity filter.
4. A gamma-ray goniometer and GeLi detectors. Standard equipment.
5. A precision recoil distance method plunger apparatus for the measurement of nuclear lifetimes in the picosecond region.
6. Three standard 30" diameter scattering chambers.

For the Relativistic Heavy Ion Program at the AGS, several beam lines are in place and shared by AGS users. Several large spectrometers may be modified and shared with High Energy Physics users. The particular device choices await outcome of in depth study by the user community of the suitability of specific devices for this physics.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: Major accomplishments have been made in the understanding of the reaction mechanism in heavy ion quasielastic and transfer reactions, the behavior of nuclei at very high spin, the production of new exotic nuclei, and in the uncovering of structure in quasimolecular systems such as $^{12}C+^{12}$, $^{24}Mg+^{24}$ and $^{28}Si+^{28}$. The first study of an electron-neutrino correlation in a forbidden beta decay contributed fundamental information on meson exchange effects in nuclei. A program on the measurement of magnetic dipole and electric quadrupole moments by innovative techniques is providing valuable and unique information on the so-called "backbend" phenomenon in high spin spectroscopy. In the realm of atomic physics, the four-stage accel-decel mode of operation has allowed exciting new ventures in the realm of quasimolecular x-ray studies.

First, following theoretical predictions of a region of very high collectivity near N=Z=40, a study was made of the rotational band structure of light strontium and zirconium isotopes. The experiments are very difficult because the nuclei in question are far from the valley of stability. Thus, gamma rays due to the decay of bands in, say, ^{84}Zr or ^{78}Sr can only be observed by demanding coincidences with both neutrons and charged particles in such reactions as $^{58}Ni(^{24}Mg,2p2n)^{78}Sr$. However, the laborious and detailed work was well worthwhile as the results did indeed show a new region of very high deformation and thus collectivity. The continuing study promises to shed considerable light on the collective behavior of nucleons in nuclei and in the behavior of nuclei at high spin.

A second highlight was the first detailed and systematic study of the giant dipole resonance (GDR) built on excited states. The giant dipole resonance can be thought of semiclassically (the Goldhaber-Teller model) as an oscillation of all the protons against all the neutrons. If a nucleus is struck by a gamma ray of the right energy, it has a high probability of being polarized into such an oscillation which finally dissipates by the emission of nucleons. Such a resonance is expected to be built on every nuclear state, but study by gamma-ray absorption inelastic scattering of electrons or hadrons allows the study of GDR's built on the ground states of stable nuclei only. Conversely, a nucleon of the right energy can polarize the nucleus, i.e., form a GDR, and cause it to emit a gamma ray ending up in the state upon which the resonance is built, thus proton capture can reveal resonances built on excited states. The first systematic studies of such phenomena were carried out by a University of Washington-BNL collaboration and were possible because of the superb resolution and counting rate capability of the BNL large volume gamma-ray detector. These studies showed a GDR built on all bound states in ^{28}Si and ^{40}Ca, and a major breakthrough in understanding came when it was found that the strength of each GDR was proportional to the probability of the state being composed of the target plus a proton. This phenomenon is now understood as is the constant of proportionality.

The BNL Tandem research staff plans to make relativistic heavy ion (RHI) research its major effort during the remainder of FY 1984 and to participate in building up the program at the AGS, including the instrumentation as a full-time base in the coming years. It is anticipated that the RHI program will expand in manpower during FY 1984 and that it will become the major nuclear physics activity at BNL in FY 1985.

Two collaborative projects have been initiated in order to gain experience with the instrumentation and become familiar with the experimental difficulties anticipated with the high energy heavy ion program. Since there is no facility which provides beams of comparable mass and energy to those expected at the AGS, the two experiments, described below, have been chosen to span the region of interest.

A collaboration was initiated with the CERN-MSU-Oxford-Rockefeller group at the ISR, CERN, to obtain and analyze data on alpha-alpha scattering. Previous data on alpha-alpha scattering at the ISR had shown anomalously high yields of events with large transverse momentum and total energy. The object of the present experiment is to corroborate the previous data where statistical errors are large and to extend the data to higher transverse momenta and total energy. Because the alpha particle is considerably larger than a proton, the energy loss in an alpha-alpha collision is significantly greater than in a p-p collision at the same relative velocity. It is conceivable, therefore, that some manifestation of quark deconfinement may be observable. In any case a comparison of the alpha-alpha and p-p data will help clarify the behavior expected in heavier ion collisions at higher energies.

A second collaboration joined Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Weizmann Institute, and Gesellschaft fuer Schwerionenforschung (GSI) in a project at the Bevalac. At low energies (<30 MeV/A), a mean field approximation in nuclear collisions is appropriate; the two participating nuclei behave as collective units of mass, A1 and A2, respectively. A characteristic of collisions in this regime is the occurrence of full momentum transfer events with considerable probability. At higher bombarding energies, say 300-500 MeV/A, the collision partners act as collections of individual nucleons and nucleon-nucleon interactions, rather than the mean fields, dominate the collision dynamics. Events with full momentum transfer are virtually nonexistent. It is the goal of the experiment to roughly map the energy region from 30 to 500 MeV/A, using fission as a meter for momentum transfer. To reach an understanding of the dynamics, it is necessary to measure where the momentum goes as completely as possible. The concept of a modular, "logarithmic" detector complex has been developed to investigate these physics questions, and it is being constructed at LANL and BNL for experimentation in 1985.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: A number of major improvements in MP-7 were made from FY 1981 to FY 1984. Accelerator tube sections were extended in length. Vacuum pumps were installed in all of the available dead sections along with drive shaft driven, generator supplied power and also a special cable shorting system that allows individual voltage conditioning of each tube section. The high voltage terminal region was improved by enclosing it in a smooth stainless steel housing in place of the original open rod enclosure, thereby greatly increasing the protection of terminal electronic components against sparks.

A remotely removable gridded lens was installed at the exit of the acceleration tubes in MP-7 in order to focus the decelerated low energy fully stripped heavy ions as they exit from the specially designed straight electrode deceleration section of the last accelerator tube section. These improvements in the four-stage deceleration mode of operation allow this accelerator system to provide the lowest energy, highest Z, totally stripped heavy ions in the world.

The development of a pulsed high current negative ion source made possible tandem accelerated heavy ion beams approximately 100 times more intense than those provided by any other tandem accelerator in the world. The development permits the use of the tandem accelerators as heavy ion injectors for AGS. The development of a specially dedicated and designed ion source system provides ^{14}C ions (a radioactive isotope of carbon) that allows MP-7 to provide the highest energy, most intense ^{14}C beams in the world for the study of nuclear structure of rare isotopes that can only be made by these ^{14}C ion beams.

In the future, a portico will be installed in MP-7 and will allow voltages as high as 18 MV and correspondingly more reliable operation, of prime importance when operating the machine as a high current heavy ion injector for the AGS synchrotron.

A tunnel will be constructed between the high energy end of the MP-7 tandem accelerator and the AGS, approximately 2000 ft long, through which the heavy ions from the tandem accelerators will be transported with a series of quadrupole focusing and dipole bending magnets in order to implement the direct injection of the AGS synchrotron for the production of relativistic heavy ions.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer:

BNL Double MP Facility
(B/A in thousands of dollars)

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
A. Accel. Operations	1,580	1,708	1,251	1,500	1,560
B. In-House Research	1,721	1,642	1,669	1,520	1,665
C. Out-of-House Research[1]	0	0	175	175	100
D. Capital Equip.	205	140	130	200	1,900
E. Gen. Plant Proj.	0	24	6	0	30
F. In-House Energy Mgmt.	0	0	285	0	0
G. Accel. Improvement & Mod.	217	0	0	0	0
H. Construction (Tandem-AGS Transfer Line)				5,000	5,300

Source of Funds	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Items A+B+C: (by Fiscal Year)					
Heavy Ion Phys.	3,126	3,300	2,675	2,755	2,870
Low Energy	175	50	420	440	455

Item D	Nuclear Physics
Item E	High Energy Physics
Item F	Energy Supply R&D
Item G	Nuclear Physics
Item H	FY 1984 Reprogrammed from ISABELLE Construction under High Energy Physics; FY 1985 under Nuclear Physics.

[1] Research effort by Tandem personnel mainly at LBL and CERN.

7. **How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?**

Answer: None.

8. **For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.**

Answer: Total staffing levels (FTE) for the Double MP Facility by fiscal year are as follows:

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
FTE	43	39	32	35	35

9. **What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?**

Answer:

BNL Double MP Facility
(Beam Hours for Research)

FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
4032	5180	5700	4000	2500

It is estimated that 6500 beam hours for research represents "full" utilization of the facility. The low beam hours in FY 1985 is due to construction.

10. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer:

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
No. Exp. Started	44	56	48	34	21
No. Exp. Continued	16	10	22	19	10
No. Exp. Completed	44	42	46	32	20

11. **What is this facility's user policy?**

Answer: The user policy is described in the following quotations from the "PROCEDURES FOR OUTSIDE USE OF THE BROOKHAVEN TANDEM VAN DE GRAAFF FACILITY".

The Laboratory expects that the accelerator will be used as much by outside scientists as by BNL staff. All requests for outside use will be reviewed by the Program Advisory Committee (PAC) before being scheduled for time on the accelerator. The PAC may give approval for a particular experiment or experimental program. The scheduling of individual runs is in the hands of the BNL local scheduling organization.

The present procedures and policies for use of the accelerator are as follows:

All requests for outside use must be made in writing and provide all the necessary information requested on the experiment request form. The PAC meets generally at three-month intervals to consider new proposals. Deadlines for proposals to be considered at these meetings are announced periodically, and decisions can be expected in six to eight weeks. If for any good reason an experimenter wants to submit an "urgent request" to do an experiment, his proposal will be reviewed immediately.

Time for nonproprietary research on the accelerator will be provided without charge.

All users and their technical support personnel who work at BNL must obtain guest appointments at the Laboratory. These may be arranged on the spot (during running time). (Nationals of Soviet-bloc countries must apply for these appointments before coming to Brookhaven.)

The experimental equipment associated with the Tandem is available to outside users. Several large diameter scattering chambers, the QDDD particle spectrometer, a time-of-flight spectrometer, the MIT-BNL Recoil Mass Spectrometer (RMS), and a NaI gamma-ray facility are available for use. These facilities are maintained by individual BNL or visiting scientists and their use by any group must be in accordance with procedures established by the "caretaker." The Tandem laboratory has a supply of 150 NIM modules, pulse-height analyzers, and computers for data acquisition, and these are available to all users subject to scheduling problems only. The placement of any large piece of experimental equipment by outside groups is subject to special consideration. Particle and Ge(Li) gamma-ray detectors, targets, and other experimental equipment subject to radiation damage will not be supplied to outside users.

The operation of the accelerator itself is completely within the charge of the operations staff. The accelerator normally runs 24 hours per day, except for scheduled and nonscheduled maintenance. All experiments are scheduled for fixed times and any maintenance that must be performed takes precedence.

12. **For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?**

    Answer: None.

13. **What is the mechanism by which specific research proposals for experiments at the facility are considered?**

    Answer: Proposals from outside users are evaluated by the Program Advisory Committee consisting of seven scientists from universities and other national laboratories. On the basis of scientific merit and suitability for the Brookhaven Tandem Facility, they select experiments for running during the half of the facility operation time allocated to outside users.

    The remainder of the accelerator time has been allocated to Research Proposals by BNL scientists on the basis of common agreement within the BNL Tandem scientific staff.

    For the future program with heavy ions at the AGS, all proposals will be submitted to the AGS Program Advisory Committee.

14. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

    Answer: Over the past 5 years, 244 outside research proposals have been submitted of which 187 were approved. It is estimated that approximately 150 research proposals by BNL scientists were also approved.

15. **How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?**

    Answer: Over the past 5 years, 253 university personnel, including 44 students, have utilized the facility. Since 1975, more than 32 graduate degrees in physics have been granted based on thesis work performed primarily at this facility.

16. **How many industrial researchers have utilized the facility over the past five years?**

    Answer: Six industrial researchers have utilized the facility over the past five years.

17. **How many researchers from foreign institutions have utilized the facility over the past five years?**

    Answer: Forty-six researchers from foreign institutions utilized the facility over the past five years.

18. **How many researchers from other agencies have utilized the facility over the past five years?**

    Answer: Two researchers from other agencies (National Bureau of Standards and the U.S. Military Academy at West Point) have utilized the Tandem Facility over the past five years.

19. What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: There are many potential future development possibilities for this accelerator facility, but there are currently no approved plans to undertake any of them beyond the activities identified in the FY 1985 budget request. New research instruments and experimental devices will be developed as the physics research program progresses. We intend to give high priority to the exploitation of the facility's unique capabilities.

20. What will be the impact of the Tandem/AGS Heavy Ion Transfer Line project (Project No. 84-R-123) on the Tandem MP Physics Facility program?

Answer: The impact of the Tandem/AGS Heavy Ion Transfer Line project will be profound. The physics program at the AGS will involve a very significant increase in the complexity of equipment and manpower requirements over the research at the Tandem. Although ten weeks per year of heavy ion beams are anticipated at the AGS, that effort will, in fact, be a full program for a large scientific community and technical support staff. It is anticipated that much of the Tandem operations staff must be involved in experimental preparations, detector development and testing, etc., during times the Tandem is not injecting AGS.

In order to provide for a highly reliable operation of the Tandem during AGS injection periods it will be necessary to run the Tandem for many weeks before AGS runs. During those periods, and with due consideration to the primary function, a low level of stand-alone Tandem physics may be possible beyond 1986. However, the Tandem facility will not provide the expected services of a "user facility" in the future. During FY 1984 and 1985 there will be major periods of Tandem down-time for upgrading the Tandem itself, and periods during which the operations crew will be totally occupied with transfer line installation. The majority of the present scientific staff is already totally engaged in the long term preparations for AGS experiments. We believe that a significant part of our Tandem outside user community will also become involved in Relativistic Heavy Ion Physics.

21. Please provide a copy of the facility's latest annual report.

Answer: The BNL MP Tandem facility does not circulate an annual report on a regular basis. However, it does submit the standard budget request document to The Department of Energy. This report which is attached contains the descriptions of scientific accomplishments which would normally be contained in an annual report.

BROOKHAVEN DOUBLE MP

EXCERPTS FROM FIELD TASK PROPOSALS
FOR HEAVY ION RESEARCH AND FACILITY OPERATIONS
WHICH DESCRIBE PROGRAMS OF 1983 AND 1984.

PRESENTED IN LIEU OF AN ANNUAL REPORT.

HEAVY ION RESEARCH

20. Detail Attachments.

a. Facility Requirements.

It is anticipated that the work entailed in this proposal will use existing Laboratory facilities and site utility services.

b. Publications.

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20. Detail Attachments cont.

b. Publications cont.

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Christensen, P. R., Pontoppidan, S., Videbaek, F., Barrette, J., Bond, P., Hansen, Ole, and Thorn, C. Scattering of ^{28}Si from ^{208}Pb measured with high resolution. Phys. Rev. C (in press).

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20. Detail Attachments cont.

b. Publications cont.

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20. Detail Attachments cont.

b. Publications cont.

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Zurmühle, R. W., Kutt, P., Betts, R. R., Saini, S., Haas, F. and Hansen, O. Resonances in elastic and inelastic scattering of ^{24}Mg + ^{24}Mg. Physics Letters 129B, 384-6 (1983).

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f. Technical Progress.

Technical Progress in FY 1983 and Expected Progress in FY 1984

I. Preamble

II. Relativistic Heavy Ion Research

  A. General Program
  B. Third International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions
  C. Experiments at Outside Facilities

    1. Collaboration at CERN: α-α Scattering at the ISR
    2. BEVALAC Low Energy Beam Line Collaboration

  D. Instrumentation

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

III. Properties and Structure of Nuclear States

- A. Introduction
- B. Gamma-Ray Studies of High Spin States Produced via Heavy-Ion Induced Fusion-Evaporation Reactions
  - 1. Neutron-Rich s-d Shell Nuclei from Fusion-Evaporation Reactions
    - a. ^{27}Na and ^{30}Al via ^{18}O + ^{14}C
    - b. ^{26}Ne, ^{26}Na via ^{14}C + ^{14}C
    - c. ^{21}O via ^{14}C + ^{9}Be
  - 2. Onset of Rigid-Body Rotation in ^{84}Zr
  - 3. High-Spin States in ^{86,88,90}Zr
  - 4. The High-Spin Structure of ^{100}Rh
  - 5. High-Spin Bands in ^{117,119}I and ^{118}Xe
  - 6. Investigation of High Spin States in $N \geq 82$ Nuclei
    - a. "Doubly-Magic" ^{146}Gd
    - b. ^{148}Gd
    - c. ^{149,150}Gd
    - d. ^{155}Er
    - e. Search for Superdeformed Shapes in ^{154}Er
  - 7. High-Spin Spectroscopy of Neutron-Deficient Bi Isotopes
    - a. High-Spin States in ^{199,201}Bi
    - b. High-Spin States in ^{197}Bi
    - c. High-Spin States in ^{195}Bi
- C. Lifetimes and Moments
  - 1. Recoil Distance Lifetime Measurements
    - a. Lifetime Measurements in the Backbend Region of ^{168}W
    - b. Enhanced E2 Transitions in A=77 Nuclei
  - 2. In-Beam Measurements of Nuclear Moments of Short-Lived Isomers
    - a. Introduction
    - b. g-Factors in the Backbend Region of ^{168}W

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

c. Sign of Quadrupole Moments of High-Spin Isomers in ^{144,147}Gd
d. g-Factors of Isomeric States in ^{193,197}Pb
e. Quadrupole Moments of the $J^{\pi}=12^{+}$ Isomers in ^{188,190}Hg

D. Radiative Capture

1. Study of the Excited State Giant Dipole Resonance Using the (p,γ) Reaction
2. Heavy-Ion Capture to ESGDR's Using the ^{12}C+^{14}C Reaction
3. Search for a Predicted Shape-Isomer in ^{32}S

E. Beta Decay and Weak Interactions

1. Nuclei Off the Line of Stability: The Decay of ^{47}Cr
2. Decay Schemes and Half-Lives

a. Half-Life of ^{32}Si
b. Decay of ^{50}V
c. The Decays of ^{50}Ca, ^{50m}Sc, ^{50}Sc and ^{47}K
d. The Decay of ^{180}Ta
e. Single Beta Decay of ^{48}Ca

3. First Forbidden Beta-Decay in Light Nuclei: ^{16}N and ^{15}C Beta Spectra and Extraction of Matrix Elements from $^{15}C(\beta^{-})^{15}N_{g.s.}$

F. General Nuclear Spectroscopy

1. Deuteron-Induced Reactions with ^{36}S Targets
2. Mass Measurements of Neutron Rich Nuclei Using ^{48}Ca and ^{36}S Targets with a ^{14}C Beam

IV. Direct Reactions

A. The General Program

B. Elastic and Inelastic Scattering

1. 180° Elastic Scattering of ^{28}Si+^{12}C and ^{28}Si+^{16}O
2. Inelastic Scattering of ^{28}Si from ^{60}Ni at 140 MeV
3. Inelastic Scattering of ^{28}Si from ^{208}Pb at 210 MeV
4. Inelastic Scattering of ^{28}Si on ^{28}Si at 151 and 180 MeV

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

5. Excitation Functions of ^{24}Mg+^{24}Mg Inelastic Scattering
6. Excitation Functions of ^{40}Ca+^{40}Ca and ^{40}Ca+^{44}Ca Inelastic Scattering
7. Elastic and Inelastic Excitation Functions of ^{32}S+^{32}S

C. Transfer Reactions

1. Study of the $\pi h_{9/2} \times \nu j_{15/2}$ and $\pi h_{9/2} \times \nu g_{9/2}$ Multiplet Structure in ^{210}Bi
2. ^{14}C Induced Reactions on ^{40}Ca, ^{58,60}Ni, ^{124}Sn, and ^{138}Ba
3. Transfer Reactions with ^{28}Si Beams
4. Analysis of ^{208}Pb (^{86}Kr,^{87}Kr) ^{207}Pb Results
5. Dynamics of Massive Transfer Reactions

V. Fusion-Evaporation Reaction Mechanisms: Evaporation Residues from Heavy Compound Nuclei

A. Possible Entrance Channel Effects in the Formation of ^{204}Rn by ^{35}Cl + ^{169}Tm, ^{48}Ti + ^{156}Gd, and ^{65}Cu + ^{139}La

B. Search for Heavy Transuranic Elements

VI. Application of Nuclear Techniques to Atoms, Molecules and Materials

A. Solid State Physics

1. Technique: Time-Dependent Perturbed Angular Distribution Measurements
2. The Relaxation Rate of Nuclear Alignment of Er in Er Single Crystal
3. Temperature Dependence of the Electric Field Gradient (EFG) in Hg

B. Atomic Physics: Measurement of Charge State Distributions of Relativistic ^{197}Au and ^{238}U After Foil Stripping

VII. Outside User Program

I. Preamble

For some years the research program undertaken by the personnel covered in this report has been almost exclusively centered on the BNL MP Tandem Van de Graaff

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

facility. The last year has been one of tumultuous change. Two new major programs of research have been undertaken by personnel from this group. Firstly, the Laser Electron Gamma Source (LEGS) program at the National Synchrotron Light Source, described in a separate FTP; secondly, the Relativistic Heavy Ion (RHI) program described in this FTP. The LEGS program has absorbed several scientists previously associated with the tandem program. The main activity of the remaining tandem group is rapidly switching to the RHI program.

The new programs offer tremendous opportunity and challenge for the future. These remarks are made to introduce the narrative material which follows. For the present we are undergoing the usual difficulties encountered in a period of rapid change. The new programs have been undertaken with essentially no increase in personnel. The supplemental budget request for FY 1985 would be used to enable a more rapid buildup of staff for the demanding program envisioned in FY 1986.

The recent emphasis of the group has been mainly in tandem physics. The tandem facility is still without peer in performance and capability. The demand for machine time from outside users, and the attendant demands on the research staff is presently as high as ever. Unfortunately, the limitations of budget and personnel require rapid attenuation of this program as funding and activity for RHI physics begin. The narrative material of this document reflects this redirection. Concrete research results are mainly, though not exclusively, in the area of tandem physics. The endeavors in the last months of some members of the group on RHI physics at the Bevalac and at CERN are of course well defined. The material on the new RHI physics at the AGS, which will delve into new unexplored regions, is, naturally, less well defined. There is little past experience to guide it; detailed theoretical study and the shaping of experimental techniques applicable to this new realm of physics are just now beginning in earnest. As these studies proceed, the great magnitude of the step in going from the Bevalac regime to the truly relativistic regime of the AGS becomes more apparent. This document presents the anticipated RHI program in as concrete form as is now possible.

In addition to the preparation for AGS physics the group will give effort to planning and proposing the physics program for the Relativistic Heavy Ion Collider. It is hoped that construction of such a collider can begin at BNL in a timely fashion consonant with the use of the enormous resources of personnel, tunnels, and equipment already in place and now available.

It should be mentioned that the planning of the anticipated RHI research program is being joined actively by many BNL High Energy physicists who will bring invaluable equipment and expertise to bear in this effort. Their efforts as well as those of the anticipated large outside user community are essential to the success of RHI physics. This group views the establishment of these cooperative efforts as an important responsibility.

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II. Relativistic Heavy Ion Research

A. General Program

BNL sponsored the Third International Conference on Ultra Relativistic Nucleus-Nucleus Collisions, September 26-30, 1983. Called "Quark Matter '83," this meeting was the third time in about four years that an international community of nuclear and particle physicists met to discuss the possibilities of colliding heavy nuclei at extremely high energies. Nearly 300 scientists participated and the proceedings will be published.

The construction of a 2000 foot long beam-transfer-line connecting the Brookhaven Tandem Facility and the Brookhaven Alternating Gradient Synchrotron (AGS) will permit oxygen and sulfur beams, initiated with the Tandems, to be further accelerated in the AGS to energies of approximately 15 GeV/nucleon. These beams will have center-of-mass energies approximately a factor of 5 greater than those presently available elsewhere in the western world. The most exciting of the experiments to be performed at the AGS with the 15 A·GeV probes will focus on phenomena associated with a fundamentally distinct form of matter. The new phase, a quark plasma, should be produced at conditions of high temperature and density where the nucleonic structure of ordinary nuclear matter disappears as a result of the deconfinement of the constituent quarks. Theoretical estimates, predicated on quantum chromodynamics and available data, indicate that the proposed experimental beam energies may approach the range required to produce this phase transition. In any case the high energies will certainly allow the investigation of nuclear matter at high baryon densities. The precise signatures by which quark matter will manifest itself is presently a subject of intense theoretical controversy, but the expectation of new discoveries is universal. The experimental equipment proposed, based in part on existing instruments, will allow rapid commencement of exploration in this new and intriguing field of research.

Two collaborative projects have been initiated in order to gain experience with the instrumentation and become familiar with the experimental difficulties anticipated with the high energy heavy ion program. Since there is no facility which provides beams of comparable mass and energy to those expected at the AGS, the two experiments, described below, have been chosen to span the region of interest.

The BNL Tandem participants in these two experiments plan to make relativistic heavy ion (RHI) research their major effort during the remainder of FY 1984 and to participate in building up the program at the AGS, including the instrumentation as a full-time base in the coming years. It is anticipated that the RHI program will expand in manpower during FY 1984 and that it will become the major nuclear physics activity at BNL in FY 1985.

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B. Third International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions

The Quark Matter '83 Conference held at BNL lasted five days and was concerned with the development of a new field of physics in which the fundamental properties of the strong interaction and the physical structure of the QCD vacuum can be studied through the macroscopic behavior of nuclear matter under extreme conditions.

Following a day of reviews of the present status of theory and experiment, the Conference moved quickly to presentations of new results. Data just becoming available from cosmic ray balloon flights and from experiments with colliding alpha beams at the ISR gave reinforcement to expectations that extremely high energy densities can be achieved in terrestrial experiments, and newly analyzed data from Fermilab on the crucial question of nuclear stopping power provided the basis for improved estimates of the required collision energies. Calculations in lattice gauge theory are now at the point where fermions can be included on the lattice, sharpening considerably the quantitative understanding of the thermodynamics of finite temperature QCD, and possible phase transitions from hadrons to a quark-gluon plasma. These advances and new results on the hydrodynamics of hot nuclear matter were treated in detail, while experimental techniques and measurement strategies were taken up in parallel sessions. Experimentalists from nuclear and particle physics found common ground for discussing very critically the existing plans for experiments and the needs for developing new detector techniques. These working sessions culminated in a round table discussion in which a panel of distinguished physicists, representing laboratories from the U.S., Japan, and Europe, made clear the diversity of approaches to this new physics, while emphasizing a strong consensus in the community regarding the need for heavy ion beams with c.m. energies on the order of 100 GeV/nucleon. (H.E. Wegner and T. Ludlam)

C. Experiments at Outside Facilities

1. Collaboration at CERN: α-α Scattering at the ISR

A collaboration was initiated with the CERN-MSU-Oxford Rockefeller group at the ISR, CERN, to obtain and analyze data on α-α scattering at $\sqrt{S}$/N-N = 31 GeV. Previous data on α-α scattering at the ISR had shown anomalously high yields of events with large transverse momentum and total energy. The object of the present experiment is to corroborate the previous data where statistical errors are large and to extend the data to higher transverse momenta and total energy. Because the α-particle is considerably larger than a proton, the energy loss in an α-α collision is significantly greater than in a p-p collision at the same $\sqrt{S}$/N-N. It is conceivable, therefore, that some manifestation of quark deconfinement may be

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observable. In any case a comparison of the α-α and p-p data will help clarify the behavior expected in heavier ion collisions at higher energies.

Data were obtained with the superconducting solenoid spectrometer (Exp. R-110) in late August; comparison runs of d-d at the same $\sqrt{S}$/N-N were taken in September. The superconducting spectrometer consists essentially of a large volume magnetic field (parallel to the beam direction) fitted with cylindrical charged particle tracking proportional wire detectors. A segmented array of Pb-glass counters and shower counters surrounds the solenoidal field and are used to measure π^0 distributions. The spectrometer encompasses the central rapidity region.

A preliminary analysis of the yields of events in α-α scattering as a function neutral total energy and neutral transverse energy has been completed. The data are in agreement with the earlier results and are now extended considerably beyond them. These data were presented at the BNL Quark Matter conference in September. Preliminary analysis to examine the sphericity and multiplicity of the events, as well as to eliminate possible sources of systematic errors (especially due to the software cuts) in addition to a detailed comparison to the p-p data, remains to be done. (C. Chasman, J.W. Olness, P. Thieberger, M. Tanaka, M. Tannenbaum and P. Haustein)

2. BEVALAC Low Energy Beam Line Collaboration

A small group was formed to join Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Weizmann Institute and Gesellschaft für Schwerionenforschung (GSI) in a collaborative project at the BEVALAC. The first goal was to develop a detector with very large range in energy and particle mass. The BNL contribution was to build the light particle detector. From August to December the group constructed a scintillator dE/dX-E detector for up to 200 MeV protons, that would fit into the rear end opening of a GSI-LANL ionization chamber. This latter was preceded by two Weizmann-LANL avalanche detectors for fission fragments. The various pieces of the system were brought together at Lawrence Berkeley Laboratory (LBL) in December for a test beam of 100 A·MeV ^{20}Ne. The fission and scintillation detectors worked very well, whereas the ion chamber was severely count-rate limited. Further development will take place and a full proposal is to be generated in the spring of 1984 for an LBL experiment encompassing several such detector modules. These will be built during FY 1984.

Apart from the technical development there is (of course) a physics idea behind the project. At low energies ($\lesssim$30 A·MeV) a mean field approximation in nuclear collisions is appropriate; the two participating nuclei behave as collective units of mass, A_1 and A_2, respectively. A characteristic of collisions in this regime is the occurrence of full momentum transfer events with

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considerable probability. At higher bombarding energies, say ≈300-500 A·MeV, the collision partners act as collections of individual nucleons, and nucleon-nucleon interactions rather than the mean-fields, dominate the collision dynamics. Events with full momentum transfer are virtually non-existent. It is the goal of the experiment to roughly map the energy region from 30 to 500 A·MeV, using fission as a meter for momentum transfer. To reach an understanding of the dynamics, it is necessary to measure where the momentum goes to as completely as possible. Hence the concept of the wide range (logarithmic) detector module. The aim is to be ready for beam time in the late summer of 1984 at LBL. (O. Hansen, C.E. Thorn, M.J. LeVine, W. Trautmann; H.C. Britt, A. Gavron, M. Fowler, J. Wilhelmy (LANL); R. Ferguson, F. Plasil (ORNL); Z. Fraenkel (Weizmann); H. Sann (GSI))

D. Instrumentation

With the anticipation of AGS running time in FY 1986 for the high energy heavy ion program, increasing effort is going toward the planning of the required experimental equipment. Present plans are outlined in the FY 1984 operations sections. The final decisions will be made in collaboration with outside users and through workshops held late this year.

III. Properties and Structure of Nuclear States

A. Introduction

The yrast and near-yrast spectra exhibited by nuclei provide an especially rich array of data which illuminate the underlying nuclear structure. This is so because relatively simple couplings between the various constituents suffice to form the lowest-lying higher spin states in a given system. Thus, fundamental information on the underlying nuclear structure is relatively more transparent for the yrast states. Heavy-ion induced fusion evaporation reactions, because of the large amount of angular momentum induced into the compound system, are particularly effective in populating yrast states.

As in past years, yrast states were studied for nuclei encompassing a large range of the periodic table (Section I.B.). The emphasis is on nuclei rather far from the stability line. The program of study of nuclei near $N = Z = 40$ continues to yield exceptionally interesting results. The aim is to explore as completely as possible the spectra of nuclei near and just above ^{40}Zr. The ultimate aim is the formation and study of that nucleus itself. It is predicted by some to be the most deformed rotational nucleus of all. The study of the rare earth region near the magic neutron number, $N = 82$, continues to provide a wealth of data for testing models describing the high-spin realm of nuclear excitation. The emphasis in this region over the past several years has shifted from the well-deformed heavier nuclei

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characterized by collective modes of excitation to the lighter transitional nuclei close to N = 82 characterized by the coupling together of a discrete number of shell model orbitals.

The fusion-evaporation reaction used to study high-spin states is particularly suited to the study of the lifetimes and moments of these states because of the accompanying high recoil velocity of the product nucleus. Over the past two years a very successful program was mounted for measuring nuclear g-factors and quadrupole moments of moderately high-spin isomers uncovered in the transitional regions around the neutron and proton shell closures of 82 particles. New techniques are being exploited that make use of the polarization effects of obliquely mounted foils on energetic recoiling ions. These measurements have provided valuable data to help in elucidating the shell model nature of these states. Such studies are described separately in Section I.C.

Inseparable from measuring nuclear hyperfine interactions is the investigation of the magnetic and electric environment at the location of impurity atoms recoil implanted into certain host materials. Since these are of significant interest to other experimenters working in this field, they are discussed separately in Section VI.A.

Since the fusion-evaporation reaction forms nuclei off the stability line, it is well suited to a search, via radioactive studies, for new nuclear species as discussed in Section I.E.2. There is a large overlap between the programs of I.B. and I.E.2, particularly when the properties of the daughter nucleus need elucidation in order to recognize the decay of the parent. This is the case, for instance, in the study of nuclei near N ~ Z ~ 40.

The study of the radiative capture of heavy-ion systems is one which is essentially unique to BNL. Now in its fifth year, the program has reached maturity and has broadened to include several quite diverse subjects on the frontiers of present knowledge. Also, the radiative capture of light ions is a powerful tool in nuclear spectroscopy. Current interest in this field is on the study of excited-state giant dipole transitions via the p,γ reaction. Each of these studies yields results of a novel and exciting nature. The program depends critically on the ability to detect high-energy gamma rays in the presence of an enormous background of lower energy gamma rays and neutrons. The success of the program stems, in large part, from the development of a state-of-the-art detector system having superior resolution and effective rejection of escape radiation from high energy showers.

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B. Gamma-Ray Studies of High Spin States Produced via Heavy-Ion Induced Fusion-Evaporation Reactions

4. Neutron-Rich s-d Shell Nuclei from Fusion-Evaporation Reactions

These investigations have employed neutron-rich target/projectile combinations together with particle-γ coincidence measurements in order to study neutron-rich off-stability nuclei. With a close-geometry particle telescope the identification of the loci for p, 2p, α, and αp emission allows unique identification (or restriction) of the fusion-evaporation exit channels leading to the final γ-emitting nuclei. A number of investigations have been pursued, as indicated below.

a. ^{27}Na and ^{30}Al via ^{18}O + ^{14}C

^{27}Na was investigated via the ^{14}C(^{18}O,αpγ)^{27}Na reaction. Particle-γ coincidences with gates set on the α, p, and αp loci establish a 159-keV γ-ray as originating from the de-excitation of the first-excited state of ^{27}Na. γ-γ coincidences disclose 4 additional states in the region 800-1500 keV. These data are appreciably more precise and complete than that available previously from the ^{26}Mg(^{18}O,^{17}F)^{27}Na* reaction.

Our analysis of the ^{14}C(^{18}O,pn)^{30}Al has been completed and published. The identification of the even-parity 3^+ (g.s), 2^+, 1^+, 3^+, 4^+ sequence of states predicted by the shell model (B. H. Wildenthal) indicates that the experimental states are "stretched" to higher energies, but the correspondence is in general good.

b. ^{26}Ne, ^{26}Na via ^{14}C + ^{14}C

A search was made for the residual nuclei, ^{26}Ne and ^{26}Na, resulting from the reaction of the newly-available ^{14}C beam on targets of 100 μg/cm^2 ^{14}C. The compound nucleus is ^{28}Mg, and the desired end products, ^{26}Ne and ^{26}Na, would be formed via the 2p and pn exit channels, respectively. The 2p loci were clearly observed in the particle detector, and particle-γ and γ-γ spectra were recorded. Analysis is in progress.

An earlier attempt to study this system via the ^{18}O + ^{10}Be reaction, which also leads to the same compound nucleus, failed primarily because the ^{10}Be could be accelerated only in the form of BeO, with the result that the ^{16}O reaction yield dominated and obscured the reactions of interest.

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c. ^{21}O via ^{14}C + ^{9}Be

A search is being made for the production of ^{21}O via the ^{9}Be(^{14}C,2p)^{21}O reaction. In order to enhance the search for the weak 2p exit channel, a 4-segment particle telescope was employed so as to determine uniquely the multiplicity of proton gated events. (The detector was obtained on loan from Daresbury via C. J. Lister.) p-p coincidences were observed, and the analysis search for 2p-coincident γ rays is in progress. (E. K. Warburton and J. W. Olness; R. L. Kozub: students, C. B. Chitwood, D. J. Fields, S. Menees, T. Campbell, M. Prahovic (Tenn. Tech. Univ.), C. J. Lister (U. of Manchester/Daresbury))

2. Onset of Rigid-Body Rotation in ^{84}Zr

The region N ~ Z ~ 38 contains very deformed nuclei exhibiting bands of states characteristic of deformed rotors. At low angular momentum nuclei are observed to have moments of inertia considerably smaller than the rigid body value, a feature due largely to the influence of pairing correlations on the interplay between the shell-model and liquid-drop model, as characterized by the microscopic and macroscopic potentials. However, at sufficiently high angular momentum, it is expected that pairing effects will be quenched, such that the macroscopic rotational energy becomes the dominant factor in determining the nuclear shape. One may therefore expect to observe a moment of inertia appropriate to that of a rigid body.

A concerted investigation of high-spin states in the transitional nucleus ^{84}Zr was undertaken in a cooperative study involving BNL and Daresbury laboratories. ^{84}Zr was formed via the ^{58}Ni(^{28}Si,2p) and ^{58}Ni(^{29}Si,2pn) reactions at bombarding energies of between 95 and 110 MeV. Gamma rays were measured by a Compton suppressed Ge(Li) spectrometer in coincidence with neutron detector arrays and charged particle telescopes, thereby identifying uniquely the observed yrast cascade in ^{84}Zr. Ordering of the cascade transitions was determined via γ-γ coincidence measurements. Angular distribution measurements together with DSAM and RDM determinations of lifetimes defined or restricted the spin-parity assignments of the levels.

The results disclose the existence of an even-parity $\Delta J = 2$ band based on the ^{84}Zr 0^+ ground state extending to $J^\pi = (34)^+$, which corresponds to a rotational frequency almost twice as high as the maximum observed previously in this mass region. Three secondary $\Delta J = 2$ bands based on $J^\pi = 2^+, 5^-$, and 6^- excited states were also observed to $J_{max} \leq 21$.

Plots of $\mathcal{J}^{(1)}$ vs. ω for the ground state band disclose two "upbends" at rotational frequencies of $\hbar\omega = 0.48$ and 0.60 MeV, in excellent agreement

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with predictions of the cranked shell model, corresponding to the crossing of the ground state band with an aligned two $g_{9/2}$ quasi-proton band and subsequently a two $g_{9/2}$ quasi-neutron band. In the high-frequency regime beyond $\hbar\omega = 0.9$ MeV ($J=18$) the previously rapid variation of $\mathcal{J}^{(1)}$ with frequency decreases and stabilizes at the rigid-body value of 25.5 MeV^{-1}, remaining constant to within 1% over a frequency range of $\Delta\hbar\omega \sim 0.5$ MeV ($\Delta J \sim 10\,\hbar$).

Within this range, transition quadrupole moments determined from lifetime measurements are $Q \sim 3.5$ eb. These data are all consistent with shape parameters of $\beta = 0.43 \pm 0.06$ and $\gamma = 3 \pm 6^\circ$, corresponding to an axially symmetric shape rotating with the rigid-body moment of inertia. We believe this is the first reported observation of this behavior. (J. W. Olness; H. G. Price (Daresbury); C. J. Lister, B. J. Varley, W. Gelletly (U. of Manchester))

3. High-Spin States in ^{86,88,90}Zr

Recent fusion-evaporation studies on nuclei near $N=Z=40$ have supported the prediction that these isotopes will exhibit considerable collectivity. Previous spectroscopic studies in this region have dealt mainly with isotopes of Kr, Rb, and Sr produced by heavy ion (HI) fusion-evaporation reactions. Studies on ^{84}Zr described in the preceding section of this report indicate the presence of considerable collectivity. Since it is often very informative to display the systematic change in structure of yrast (or near yrast) states as a function of N(Z) in a series of isotopes (isotones), these studies have been extended to include the isotopes, ^{86,88,90}Zr. These results will then complete the study of even Zr isotopes from one end of the $g_{9/2}$ neutron shell to the other.

^{88}Nb and ^{90}Nb both have $J^\pi = 8^+$ ground states which decay to ^{88}Zr and ^{90}Zr by β^+/EC decay. Because of the high ^{88,90}Nb spins the low-lying high-spin ($J \leq 9$) structure of both Zr nuclei can be investigated by β^+/EC decay; such studies have been made up to ~ 3.4-MeV excitation in ^{88}Zr and 5.6-MeV excitation in ^{90}Zr. In fact, ^{90}Nb $(\beta^+/\mathrm{EC})^{90}$Zr, most recently studied at BNL by Warburton and Alburger (last year's FTP) provides all that is known about the high-spin levels of ^{90}Zr. This is rather surprising since ^{90}Zr, being of special interest because it is doubly magic, lies in the valley of stability and is relatively easy to produce. Spectroscopy of high spin states in ^{88}Zr has been previously investigated using the $^{86}\mathrm{Sr}(\alpha,2n)^{88}\mathrm{Zr}$ and $^{89}\mathrm{Y}(p,2n)^{88}\mathrm{Zr}$ reactions. These studies provided information on ^{88}Zr levels up to ~ 6-MeV excitation and a possible spin of $J=14$.

The present study used the $^{74,76}\mathrm{Ge}(^{18}\mathrm{O},4n)^{88,90}\mathrm{Zr}$ reactions and the $^{60}\mathrm{Ni}(^{29}\mathrm{Si},2pn)^{86}\mathrm{Zr}$ reaction. Consideration of the kinematics led us to expect that considerably higher excitation energies and spin values would be reached than in the previous studies. This was indeed the case and states up to $J=21$ and E_x

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≈ 12.9 MeV-excitation were found. Detailed analysis of the data is in progress as are shell-model calculations for comparison. (E. K. Warburton, J. W. Olness; J. A. Becker (LLL); C. J. Lister (U. of Manchester); R. W. Zurmühle (U. of Penn.))

4. The High-Spin Structure of ^{100}Rh

High-spin states of ^{100}Rh were populated with the reactions ^{99}Ru(α,2np) and ^{98}Mo(^{6}Li,4n). The de-excitation gamma transitions were studied with Ge(Li) detectors in prompt and time dependent coincidence. Gamma ray angular distibutions were also measured. As a result, 14 new levels spanning spins up to I=16 built on the 5^+ 4.5 min isomer at 107 keV were established, and a half-life of $T_{1/2} = 120 \pm 5$ nsec was determined for the 7^+ state at 111.9 keV. The rotor-plus two-quasiparticle model was used to describe the observed level structure. The p-n interaction was found to be of negligible effect. On the other hand, the introduction of a soft core was essential. The application of the VMI model with the parameters extracted from the ^{98}Ru core yielded remarkably good agreement. This is the first time that the anomalous VMI root ($\mathcal{J}_c < 0$) was applied to a doubly odd nucleus. (C. Baktash, P. Thieberger; M. Behar, A. Ferrero, G. Garcia-Bermudez, A. J. Kreiner, A. O. Macchiavelli, and M. A. J. Mariscotti (CNEA, Argentina))

5. High-Spin Bands in ^{117,119}I and ^{118}Xe

Excited states in ^{117}I, ^{118}Xe, and ^{119}I were populated in the reactions ^{106}Pd + ^{16}O and ^{108,110}Cd + ^{12}C using ^{16}O beams from the BNL Tandem Van de Graaff facility and ^{12}C beams from the 225 cm cyclotron at the Research Institute of Physics in Stockholm. The ground-state band in ^{118}Xe was observed up to the (18^+) level and the $11/2^-$ bands in ^{117}I and ^{119}I up to the $(35/2^-)$ and $(43/2^-)$ levels, respectively. The structure of the bands in the I isotopes is interpreted as an $h_{11/2}$ proton coupled to an even-even band structure in Xe, and the band crossings are interpreted as a manifestation of $h_{11/2}$ neutron orbitals. (E. der Mateosian, P. Thieberger; A. Kerek, K. Honkanen (Research Institute of Physics, Sweden); T. Lönnroth (University of Jyväskylä, Finland))

6. Investigation of High-Spin States in $N \geq 82$ Nuclei

Interest continues at a high level in the nuclear structure characteristics of nuclei in the vicinity of the "doubly-magic" nucleus (Z=64, N=82) ^{146}Gd. In the near neighbors of ^{146}Gd, the structure is dominated by shell-model considerations in which angular momentum alignment of individual nucleon spins along a common axis plays a major role. Odd neutron neighbors exhibit systematic features in their level structures which can be associated with coupling of the odd neutrons to (proton particle-hole) core excitations of ^{146}Gd. Because of the persistent

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recurrence of recognizable patterns in the yraststructureof these $Z=64$, $N>82$ nuclei, as well as in neighboring nuclei of higher Z, it is important to obtain as complete an understanding of the "base" nuclei as possible. ^{146}Gd and its near neighbors are excellent examples for studies of this sort. In ^{146}Gd, for example, the low-lying level structure ($I \leq 16^+$, $E_{excit.} \leq 6.4$ MeV), established mainly at Julich, can be understood largely in terms of proton particle-hole configurations which involve $h_{11/2}$ particles, $g_{7/2}$ or $d_{5/2}$ hole couplings, as well as more complicated 2 particle-2 hole configurations of these same proton orbitals. The challenge now is to experimentally establish the level structure above spin 16 and to assign proper configurational descriptions to these states. It is an open question as to what extent neutron particle-hole or 2 particle-2 hole excitations will combine with selected proton excitations to form high spin, yrast states.

It is apparent from work described elsewhere in this report that the occurrence of long-lived isomers (nanosecond half-lives) in this region provide important opportunities to measure g-factors or quadrupole moments. These electromagnetic moments can play a decisive role in answering questions which relate to the structure of these states.

a. "Doubly-Magic" ^{146}Gd

Levels of ^{146}Gd were populated by means of the ^{120}Sn(^{30}Si,4n)^{146}Gd reaction at 140 MeV. Analysis of extensive gamma-gamma-time coincidence data has thus far revealed many transitions above the previously assigned 16^+ state at 6.4 MeV which play a prominent role in the yrast cascade. Even at low spin, interesting problems remain. At present, all known yrast states with $J \leq 9$ have odd parity. As in ^{208}Pb, the first excited state at 1579 keV is 3^-. Although the 2^+ state is known to be at 1973 keV, neither it nor any other even parity state has been observed in heavy ion induced reactions. Evidence is seen here for possible γ-ray branching into the 2^+ state. Observation of higher spin members, 4^+, etc. in a low-lying even spin, even parity sequence is of importance for purposes of assigning a configuration (presumably proton) to these states. Work is continuing on this nucleus. (A. W. Sunyar, E. der Mateosian, O. C. Kistner; C. Baktash (ORNL); D. Horn (Chalk River); C. J. Lister (U. of Manchester))

b. ^{148}Gd

The completed analysis of ^{148}Gd γ-γ coincidence and time-γ correlation data was reported in last year's FTP. Certain remaining puzzles in the high-spin level structure have necessitated a more complete examination of the gamma ray angular distributions. Angular distribution coefficients, important for multipolarity and spin assignments, have now been determined for over 60 gamma transitions in this complex scheme. Preparation of a publication is continuing.

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(E. der Mateosian, O. C. Kistner, A. W. Sunyar; C. Baktash (ORNL); D. Horn (Chalk River); C. J. Lister (U. of Manchester))

c. ^{149,150}Gd

The level scheme studies described in previous FTP's are completed. A manuscript is planned for publication. (E. der Mateosian, O. C. Kistner, A. W. Sunyar; C. Baktash (ORNL); D. Horn (Chalk River); C. J. Lister (U. of Manchester))

d. ^{155}Er

Measurements of the magnetic g-factors of the $13/2^+$ isomeric states found in ^{155}Er and ^{157}Yb were reported in last year's FTP. In ^{155}Er this state decays with a half-life of 35 nanosec via a two step (31 keV E1, 531 keV E2) cascade to the $f_{7/2}$ ground state. While the $i_{13/2}$ neutron orbital is certainly a large component in the configurational description for this state, the low energy of 3^- core excitations in this mass region suggests that the $(3^- \times f_{7/2})_{13/2^+}$ particle-core excitation could represent a significant admixture into the $13/2^+$ state. A crossover E3, if observed, could shed some light on this question. Accordingly, a search for this E3 crossover was made, using the ^{121}Sb(^{37}Cl,3n)^{155}Er reaction at 146 MeV. Two Ge detectors were placed in delayed coincidence, and the yield of the possible 562 keV E3 gamma ray was compared to the cascade 531 keV E2 transition. An upper limit of 1% was placed on the intensity of the E3 crossover. Because of model-dependent phase factors, no straightforward interpretation of the particle-core excitation admixture is possible without further information. Additional work to clarify the level structure above I = 45/2 continues. (A. W. Sunyar, O. C. Kistner, M. Rafailovich; G. Sprouse and S. Vajda (SUNY-Stony Brook))

e. Search for Superdeformed Shapes in ^{154}Er

A collaborative experiment with several outside user groups (see below) is being prepared to search for the presence of high energy (~ 1.5 MeV) correlated γ-rays which may originate from superdeformed states at high spin in ^{154}Er. This experiment will utilize 12 NaI detectors to serve as a multiplicity filter, to enhance the selectivity of the high quality individual line spectra obtained with six Compton-suppressed Ge detectors. The nucleus will be populated via the ^{124}Te(^{34}S,4n) reaction at about 160 MeV bombarding energy. It is expected that this experiment will extend the yrast structure well beyond the I=37 ℏ limit established by the earlier BNL work. It is interesting to note that the aligned spin available from valence neutrons and protons in ^{154}Er is exhausted at spin 37 ℏ. If the aligned coupling scheme continues above this spin, neutrons will have to be excited across the N=82 shell closure, the result of which would be a significant

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oblate deformation. The possibilities for observing especially interesting effects in this extended yrast region are very good. (O. C. Kistner, A. W. Sunyar, E. der Mateosian; C. Baktash, I. Y. Lee, Y. Schutz, N. R. Johnson (ORNL); D. G. Sarantites, K. Honkanen, T. Senkow (Wash. Univ.); L. L. Riedinger, A. J. Larabee, L. H. Courtney (U. of Tenn.); J. X. Saladin (U. of Pittsburgh))

7. High-Spin Spectroscopy of Neutron-Deficient Bi Isotopes

a. High-Spin States in ^{199,201}Bi

The systematic investigation of odd-A bismuth has been extended to lower neutron numbers by the studies of ^{199,201}Bi. The isotopes were populated by the ^{194,196}Pt(^{10}B,5nα)^{199,201}Bi reactions. A large number of excited states were found, which can be interpreted to arise from weak coupling of the yrast 0^+, 2^+, 4^+, 5^-, 7^-, 9^-, and 12^+ two-quasiparticle states, as well as 11^-, 14^+, (15^-) and 16^+ four-quasiparticle states in the even-A Pb core, to the odd $h_{9/2}$ proton orbital. A new method of calculating the excitation energy of three-quasiparticle states in odd-A Bi isotopes, called the "cluster-interaction" method, has been developed. These calculations have been found to give satisfactory agreement with experiment. Four unusually fast electric dipole transitions of the type ($13/2^+$ $13/2^-$,$11/2^-$) have been found. No trace was found of the "intruder" proton-hole excitation, $\pi j_0^2 \to h_{11/2}^{-1}$, the search for which was the original motivation of this study. (E. K. Warburton; W. F. Piel, Jr., T. Chapuran, K. Dybdal, D. B. Fossan, T. Lönnroth (SUNY-Stony Brook); D. Horn (Chalk River))

b. High-Spin States in ^{197}Bi

High-spin states in ^{197}Bi were populated in the bombardment of ^{192}Pt with ^{10}B ions. The "cluster-interaction" method, introduced in the studies of ^{199,201}Bi (see preceding section), was tested for the yrast states of this nucleus and it was found that the mean and rms deviations from the predictions are only −45 and 70 keV, respectively. As in the heavier isotopes, two very fast E1 transitions were found. It is suggested that they originated from the allowed E1 $\pi i_{11/2} \times \nu 2^+ \to \pi h_{9/2} \times \nu 2^+$ admixtures in the $\pi i_{13/2}$ proton state. The influence of the deep-lying neutron holes $\nu f_{9/2}^{-7}$ and $\nu h_{9/2}^{-7}$ has been discussed in previous years FTP's where evidence for a high-spin isomer involving the $\pi i_{13/2}$ proton was presented. As for the heavier Bi isotopes, no evidence of the $\pi h_{11/2}^{-1}$ proton-hole intruder state was found. (E. K. Warburton; T. Chapuran, K. Dybdal, D. B. Fossan, T. Lönnroth, W. F. Piel (SUNY-Stony Brook); D. Horn (Chalk River))

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c. High-Spin States in ^{195}Bi

In a further attempt to locate the $\pi h_{11/2}^{-1}$ proton-hole "intruder" state in neutron-deficient Bi isotopes, excited states of ^{195}Bi were populated by the bombardment of ^{182}W with ^{19}F ions. States up to the (probable) $29/2^-$ isomer have been observed. The $\pi i_{13/2}$ proton state, $13/2^+$ has been observed to be the first excited state with a half-life of about 20 ns yielding for the first time a direct measurement of the $B(M2; \pi i_{13/2} \rightarrow \pi h_{9/2})$ transition rate. Although the experiments are not yet completed, it seems that even in ^{195}Bi, with 14 holes in the N=126 shell, there is no evidence for proton core excitations. (E. K. Warburton; T. Lönnroth, D. B. Fossan, M. Q. Quader, M. Lovelock, W. F. Piel, Jr., S. Vajda (SUNY-Stony Brook); T. Chapuran (U. of Pa.))

C. Lifetimes and Moments

1. Recoil Distance Lifetime Measurements

a. Lifetime Measurements in the Backbend Region of ^{168}W

Lifetimes in ^{168}W were measured using the recoil distance method (RDM). States in ^{168}W were populated via the ^{141}Pr(^{31}P,4n) reaction at 158 MeV beam energy. Of particular significance is the discovery of an unusually slow E2 transition of 520 keV at the backbend of the yrast line. This transition, which connects the 12^+ state of the rotation aligned 2-quasiparticle $i_{13/2}$ neutron band with the 10^+ state of the rotational ground state band has a lifetime of 87 psec, an indication of very little mixing between the bands. An interaction matrix element of $10<V<19$ keV is deduced which is in agreement with cranked shell model calculations in this region. In addition, the lifetime of the 14^+ to 12^+ transition in the aligned band was measured as 38 psec, a result of the small transition energy of 288 keV. The discovery of these lifetimes makes ^{168}W a rare candidate for measuring magnetic g-factors through the backbend region by application of the recently developed multi-tilted foil technique thereby providing an important test of the rotation alignment model. Measurements of these g-factors are presently in progress and are reported in Section III.C.2"In-Beam Measurements of Nuclear Moments...". These lifetime measurements also result in an unambiguous reordering of the previously published level scheme. A paper on this work has been submitted to The Physical Review, Rapid Communications for publication. (O. C. Kistner, M. H. Rafailovich; G. D. Dracoulis and G. D. Sprouse (SUNY-Stony Brook))

b. Enhanced E2 Transitions in A=77 Nuclei

Previous work at BNL utilizing the He-jet system disclosed levels of ^{77}Rb via study of the ^{77}Sr(β^+)^{77}Rb decay. Subsequently, on-line

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particle-γ coincidence measurements of ^{77}Sr and ^{77}Rb populated by ^{40}Ca + ^{40}Ca reaction via the 2pn and 3p exit channels, respectively, revealed a yrast structure corresponding to major shape deformation and collective behavior.

These investigations have now been extended to include RDM measurements of lifetimes in ^{77}Sr and ^{77}Rb using the precision BNL Plunger. Gamma rays were detected at 0° relative to the ^{40}Ca beam direction using a Compton suppressed Ge spectrometer. Preliminary results reveal enhanced B(E2) transition rates, in the range 50-100 W.u., an indication of very strong collective behavior. Analysis of the data is continuing. (J. W. Olness; C. J. Lister, B. J. Varley (U. of Manchester); H. G. Price (Daresbury); L. Luehmann, K. P. Lieb (U. of Gottingen))

2. In-Beam Measurements of Nuclear Moments of Short-Lived Isomers

a. Introduction

The program begun last year to measure magnetic and electric hyperfine interactions of short-lived high spin isomers has continued. Of particular interest is the application of the newly developed multi-tilted foil techniques to the measurement of g-factors and the sign of quadrupole moments of isomeric states with lifetimes down to the tens of psec range. These measurements make use of the phenomenon that ions emerging from a thin foil (carbon) tilted about an axis perpendicular to the beam direction will be effectively polarized in the direction of the tilt axis. In the limit of very closely spaced foils, the nucleus will experience an average Larmour precession in an intense effective magnetic field pointing parallel to the tilt axis and in the sense of the tilt rotation, an effect ideally suited to the measurement of magnetic g-factors by the method of integral precession. As the carbon foils are spaced further apart, the atomic polarization will be transferred to the nucleus. Implantation of these polarized nuclei into a suitable single crystal host will then provide the interesting capability of measuring the sign of the quadrupole moment of short-lived isomeric states.

Two measurements of high current interest using these techniques are presently in progress at the BNL Tandem facility: i) Experiments are being conducted to determine the g-factors of yrast states in the backbend region of ^{168}W. The lifetimes of these states (see section C.1.) are particularly suitable for application of the tilted foil technique. These measurements will provide an important test of the rotational alignment model. ii) Measurements are being made to determine the sign of the electric quadrupole moments of high spin isomers in Gd isotopes by employing the nuclear polarization aspect of the tilted foil technique. Much experimental and theoretical effort has been devoted recently to understanding the evolution of the shape of the nucleus as it is excited to states of ever

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increasing angular momentum. The current view is that nuclei, which are spherical or prolate at low spin will become increasingly oblate with increasing spin. This comes about as a result of the alignment of increasing numbers of valence nucleons along the spin axis which then polarize the core to an oblate shape. Such behavior is assumed to take place in ^{147}Gd where the absolute magnitude of the electric quadrupole moment of three isomeric levels has been shown to increase with spin. However, the sign of the deformation (negative for oblate and positive for prolate) can be determined only by measuring the sign of the quadrupole moment. This requires preparation of the nucleus in a polarized state, a requirement that can now be attained for short-lived isomeric states via the tilted foil technique.

Using the more conventional techniques of time differential perturbed angular distribution measurements in an externally applied magnetic field, magnetic g-factor measurements of high spin isomers (29/2) in the neutron deficient odd Pb isotopes have been expanded to include ^{193}Pb and ^{197}Pb. These measurements are an effective test of the expected shell model assignments of aligned $i_{13/2}$ neutron orbitals. Measurements of the static electric quadrupole moment in the neutron deficient Hg isotopes of 188 and 190 have been completed and have provided useful information concerning nuclear deformation parameters in this region.

As in the past, these measurements have yielded some significant solid state results which are presented in a latter section.

b. g-Factors in the Backbend Region of ^{168}W

The multi-tilted foil technique is being applied to measure g-factors in the backbend region of ^{168}W. According to the rotational alignment model description of the "backbend" phenomenon in deformed rotational nuclei in this region, the g-factor of the yrast levels at the backbend should drop sharply from a value of approximately $+Z/A$ to near zero, or even become negative. This is a consequence of the fact that as a nucleus is exited up the yrast band to around 12 to 14 $\hbar$ units of spin,it becomes energetically more favorable for the angular momentum of the spinning prolate positively charged nuclear core to be taken up by a pair of rotation aligned $i_{13/2}$ neutrons. A measurement of these g-factors would provide an important test of the rotational alignment calculations which are sufficiently detailed now to warrant a precession measurement. Unfortunately because of lifetime limitations, these g-factors are very difficult to measure and only a few measurements with relatively large errors have been reported. As described in section C.1. of this report, the lifetimes of the 14^+ and 12^+ yrast states in ^{168}W, 38 and 87 psec, respectively, are by far the longest known to date and are particularly well suited for g-factor measurements by the tilted foil technique. A preliminary run was made which established the suitability of the ^{141}Pr(^{31}P,4n)^{168}W

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reaction using self-supporting stretched target foils of 1 mg/cm^2 Pr metal. The target and ^{208}Pb stopper were mounted in a specially designed recoil distance device which was capable of being rotated so that the beam could make an angle of ± 25° relative to the target-stopper plane. A cassette of some 10 carbon foils could be positioned between target and stopper while adjusting their separation to the required recoil distance. A relative measure of the g-factor is obtained by measuring the integral precession of the gamma-ray anisotropy while alternately tilting the target at plus and minus 25° to the beam direction. A calibration of the average effective magnetic field will be made by measuring the precession angle for a known g-factor in a neighboring W isotope. (O. C. Kistner, M. H. Rafailovich; G.D. Dracoulis (SUNY-Stony Brook); Y. Niv (Rutgers Univ.))

c. Sign of Quadrupole Moments of High-Spin Isomers in ^{144,147}Gd

The technique of polarizing nuclei by allowing them to recoil through an array of tilted carbon foils was successfully applied to a measurement of the sign of the quadrupole moment of the 130 nsec 10^+ isomer in ^{144}Gd. In this technique, the atomic polarization imparted to the ions as they exit from a tilted carbon foil is transferred to the atomic nucleus while the recoiling ion traverses the space between two successive foils. The isomer was populated by bombarding a 1 mg/cm^2 metallic foil of enriched ^{120}Sn with a pulsed beam of 145 MeV ^{28}Si ions. The recoiling nuclei, after passing through an array of twenty 5-8 μg C foils, the planes of which made an angle of 30° to the beam direction, were stopped in a single crystal of Gd. The sign of the quadrupole moment was shown to be negative, in agreement with model calculations. The degree of polarization in this experiment was determined to be 15%.

Preliminary measurements were made for the more interesting case of the $49/2^+$ isomeric state in ^{147}Gd populated by the ^{124}Sn(^{28}Si,5n) reaction. However, with the Ge detectors in hand, sufficient counting statistics could not be accumulated in a reasonable length of time to obtain a definitive result. It is planned to repeat the experiment using 4 anti-Compton shielded Ge detectors (supplied by way of a collaboration with ORNL). The expected improvement in photopeak to background ratio that can be thereby achieved should make it possible to determine the sign of the quadrupole moment in 4-5 days of beam time. (O. C. Kistner, M. H. Rafailovich, C. Chasman; E. Dafni, G. Goldring, M. Hass (Weizmann Inst. of Science, Israel); S. Vajda (Rutgers Univ.))

d. g-Factors of Isomeric States in ^{193,197}Pb

Work has continued on completing the systematics of g-factor measurements of the isomeric 29/2 states in the odd lead isotopes. If the

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expected $(i_{13/2})^{-3}$ configuration is correct, the g-factors of these states should all be similar to the experimental g-factor for the known single particle $i_{13/2}$ neutron state in ^{205}Pb, g = -0.15(1), as was the value of g = -0.185(17) reported last year for ^{195}Pb. The isotopes of ^{197}Pb and ^{193}Pb were each populated by (^{16}O,xn) reaction on thick targets of isotopically enriched metallic tungsten using a pulsed beam of ~100 MeV ^{16}O. Preliminary analyses gave a result of g = -0.163(8) for the 29/2 state in ^{197}Pb, in good agreement with the above assignment. For the case of ^{193}Pb, two distinct half-lives were observed with values of approximately 600 nsec and 30 nsec. Larmour precessions corresponding to a g-factor of $|g| = 0.273(14)$ for the longer lived state were observed. A sufficiently detailed level scheme placing these isomers is not yet available; however, the observed g-factor clearly is inconsistent with a $(\nu i_{13/2})^{-n}$ configuration. Analyses to determine the g-factor of the shorter lived state continues. (M. H. Rafailovich, O. C. Kistner, G. Garcia-Bermudez; G. Goldring, E. Dafni (Weizmann Inst. of Science, Israel); G. D. Sprouse and S. Vajda (SUNY-Stony Brook))

e. Quadrupole Moments of the $J^{\pi}=12^{+}$ Isomers in ^{188,190}Hg

The two isotopes of mercury were populated via the ^{164}Dy(^{28}Si,4n)^{188}Hg and ^{175}Lu(^{19}F,4n)^{190}Hg reactions using pulsed beams of 136 and 91 MeV, respectively. The mercury isotopes were allowed to recoil into a host lattice of a drop of frozen mercury which was cooled below the freezing point by mounting it on the copper cold finger of a Joule-Thompson cooling device. Experience has shown that the mercury usually solidifies, upon slow cooling, into a single crystal with the c-axis oriented perpendicular to the copper surface. The quadrupole precessions were observed with the c-axis of the crystal oriented at 45° to the beam direction in the plane of the detectors. The crystal orientation was verified by checking that the precession of the anisotropy vanishes when the c-axis is parallel to the beam direction.

The values obtained for the quadrupole moments, Q(188) = 0.91(11)b and Q(190) = 1.18(14)b fall on a line showing a smooth decrease in in going from ^{198}Hg to ^{188}Hg. This behavior, together with known B(E2) transition rates in ^{198}Hg, is consistent with a rotation alignment model calculation based on a constant β deformation parameter of 0.13 and a γ deformation parameter which varies from -54 degrees at ^{198}Hg to -46 degrees at ^{188}Hg. An anomalously low $12^{+} \rightarrow 10^{+}$ B(E2) in ^{188}Hg is clearly not reflected by the value of $|Q|$ for the 12^{+} state and can be explained by a pair of rotation aligned $h_{11/2}$ protons admixing with the 10^{+} state. The explanation must therefore lie in the configurational make up of the 10^{+} state, a likely possibility being the intrusion of a rotation aligned pair of $h_{11/2}$ protons. (M. H. Rafailovich, O. C. Kistner; G. D. Dracoulis, T. Lönnroth, S. Vajda (SUNY-Stony Brook))

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D. Radiative Capture

1. Study of the Excited State Giant Dipole Resonance Using the (p,γ) Reaction

The BNL/University of Washington, Seattle collaboration has studied excited state giant dipole resonances (ESGDR's) using the $^{27}Al(p,\gamma)^{28}Si^*$ reaction, which has provided new information about the ESGDR properties for states up to 14 MeV in ^{28}Si. This work not only established the existence of ESGDR's but also showed that resonance widths depend weakly upon the nature of the final state. Another interesting result was the discovery of a simple relationship between the integrated inverse strength $I = \Sigma(2J+1)\sigma(\gamma,p_o)dE$ and the proton transfer strength $\Sigma(2J+1)C^2S$, summing over all transfers. It was found that these two quantities are related by the proportionality constant K, $I = K\Sigma(2J+1)C^2S$, where K is 22 MeV mb.

The continuing study of ESGDR's has taken two major directions. The first has been the investigation of the ESGDR properties for states above 14 MeV in ^{28}Si using the abovementioned relationship to predict single-particle strength where no experimental stripping information exists. This is part of an ongoing analysis of the $^{27}Al(p,\gamma)^{28}Si^*$ data.

The second effort is the measurement of ESGDR properties in nuclei heavier than ^{28}Si. Given even the excellent energy resolution of the BNL-MKIII NaI(Tl) detector, 2% at 20 MeV gamma-ray energy, there are only a few prospective targets where final states above 6 MeV can be resolved. Experiments measuring the $^{39}K(p,\gamma)^{40}Ca$, $^{40}Ca(p,\gamma)^{41}Sc$, $^{59}Co(p,\gamma)^{60}Ni$, and $^{60}Ni(p,\gamma)^{61}Cu$ reactions are planned before the shutdown of the BNL Tandems for the intershield upgrade.

The $^{39}K(p,\gamma)^{40}Ca^*$ reaction will provide new ESGDR excitation functions for states up to 8.5 MeV in ^{40}Ca. A comparison can then be made between the integrated (γ,p_o) cross section and the published proton transfer strength for the various final states in ^{40}Ca in order to determine the value of the proportionality constant K. A measurement of the $^{40}Ca(p,\gamma)^{41}Sc^8$ reaction will show if the addition of a valence proton to the closed 2s1d core of ^{40}Ca perturbs the ESGDR properties found in the $^{39}K(p,\gamma)$ reaction. In comparing the $^{27}Al(p,\gamma)^{28}Si$ reaction results with $^{28}Si(p,\gamma)^{29}P^8$ data, the same value for the constant K was found. It will be interesting to see whether the same result will be found for the $^{59}Co(p,\gamma)^{60}Ni$ and $^{60}Ni(p,\gamma)^{61}Cu$ reactions. (D.H. Dowell, A.M. Sandorfi; K.A. Snover (U. Washington, Seattle))

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2. Heavy-Ion Capture to ESGDR's Using the ^{12}C+^{14}C Reaction

As a continuation of previous work at BNL, a study of the radiative capture of ^{12}C by ^{14}C has been made at the BNL Tandem Van de Graaff facility. Two separate experiments using carbon beams from the MP7 tandem were performed. In the first experiment a ^{14}C beam of up to 500 particle-nA was used with a ^{12}C target; in the second run a ^{12}C beam bombarded a ^{14}C target. High energy gamma-ray spectra were obtained using the BNL MKIII NaI(Tl) spectrometer at $\theta_\gamma=90^\circ$ for beam energies ranging from 11.6 to 15.6 MeV.

Strong radiative transitions were observed to excited states in ^{26}Mg from 4.3 to 5.7 MeV as well as weaker decays to the low-lying and ground states. In a preliminary analysis the distribution of capture strength was found to be well correlated with that seen in the ^{12}C(^{18}O,α)^{26}Mg reaction. A connection between (p,γ) capture strength to excited state giant dipole resonances (ESGDR's) and (^{3}He,d) single-particle transfer strength was observed in recent BNL/University of Washington, Seattle, work using the ^{27}Al(p,γ)^{28}Si reaction. The existence of an analogous relation between (^{12}C,γ) capture into ESGDR's and (^{18}O,α) strengths would be quite surprising.

A lineshape analysis of the ^{14}C(^{12}C,γ)^{26}Mg* gamma-ray spectra to obtain the final excitation functions is in progress. The γ-decay to the final states in ^{26}Mg from 4.3 to 5.7 MeV appears over a broader range of center-of-mass entrance channel energies than does the decay to the low-lying states, especially the ground state. Whether an intermediate ESGDR is involved in the heavy-ion radiative capture and whether its decay is statistical or not, will be determined from the final excitation functions and statistical-model calculations. (A.M. Sandorfi, D.H. Dowell; L. Ricken, (SUNY at Stony Brook and RUB Bochum, Germany))

3. Search for a Predicted Shape-Isomer in ^{32}S

In a recent BNL experiment, the heavy-ion radiative capture reaction ^{12}C(^{16}O)^{28}Si was used to study excited state giant dipole resonances (ESGDR's) built on the prolate states of ^{28}Si. The transitions to these prolate states, which have a 0^+ bandhead at 6.7 MeV excitation, were strongly enhanced in this reaction. The excitation functions for these transitions, when plotted as a function of photon energy, exhibited structures remarkably similar to those observed in photonuclear experiments studying the giant dipole resonance of the ground state (GDR) of ^{28}Si. The enhancement of the observed decays to prolate states in this reaction was seen as resulting from the inherently prolate heavy-ion entrance channel.

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Several recent theoretical calculations have predicted the existence of shape-isomeric states in many sd-shell nuclei. Although the various calculations utilize quite different techniques, all agree quite well for ^{32}S and lead to the conclusion that the 8.507 MeV state must be the 0^+ bandhead of a set of levels with a very strong prolate deformation (with an intrinsic quadrupole moment of 2 eb, which is about a factor of seven larger than that of the ground state rotational-band of ^{32}S). If this is indeed the case, we would expect to see enhanced E2 transitions in the heavy-ion capture reaction $^{16}O(^{16}O,\gamma)^{32}S$. This reaction was studied on MP7 with the MKII and MKIII gamma-ray spectrometers at $\theta_\gamma=90^\circ$ and 45°, respectively, using an Al_2O_3 target. The cross sections observed were considerably smaller than those of the $^{12}C(^{16}O,\gamma)$ reaction, and no strong transitions were observed to final states in the region of 7-9 MeV in ^{32}S. Since dipole transitions from the $^{16}O+^{16}O$ entrance channel to 0^+ final states are forbidden, a giant quadrupole resonance (GQR) must supply the gamma-ray strength if transitions to the 8.5 MeV state are to be observed. Hauser-Feshbach calculations, assuming purely statistical particle widths, have confirmed that if a GQR, similar to that of the ^{32}S ground state, was built on a prolate state at 8.5 MeV, the associated transitions should be observed in $^{16}O(^{16}O,\gamma)^{32}S(8.5)$. Evidently, either the excited state quadrupole strength is much more spread out than that of the ground state, or the calculated deformation of the 8.5 MeV level in ^{32}S is in error. (A.M. Sandorfi; L. Ricken (SUNY at Stony Brook and RUB, Bochum, Germany))

E. Beta Decay and Weak Interactions

1. Nuclei Off the Line of Stability: The Decay of ^{47}Cr

The general program of studying nuclei off the line of stability using heavy ions from the Tandem Van de Graaff together with the He-jet system has continued. The isotope ^{47}Cr was produced in the $^{9}Be(^{40}Ca,2n)^{47}Cr$ reaction by the 118-MeV ^{40}Ca bombardment of a Be target. A gamma ray of 88 keV corresponding to an activity with a half-life of 550(1) ms was observed. On the basis of this previously unobserved gamma-ray a decay scheme was proposed in which the beta-ray branching of ^{47}Cr to the first-excited state of ^{47}V is 1.8%, the remainder going to the ground state. (D.E. Alburger and J.W. Olness; T.W. Burrows (NNDC))

2. Decay Schemes and Half-Lives

a. Half-Life of ^{32}Si

Measurements on the decay rate of ^{32}Si, described in detail in last year's report, were continued at 3 to 4 week intervals by comparing the beta-ray emission rate with that of a ^{36}Cl standard sample. After nearly two years, a total of 30 points were taken which indicated a ^{32}Si half-life in the

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vicinity of 180-200 years. This very preliminary result is inconsistent with two tandem accelerator measurements of 101(18) and 107(18) years obtained at Argonne National Laboratory (with BNL collaboration) and at the University of Rochester, respectively. Measurements at one-month intervals for one or two more years will be continued in order to obtain a convincing result. This half-life is important for a number of geological studies. (D.E. Alburger; G. Harbottle and E.F. Norton (Chemistry Dept.))

b. Decay of ^{50}V

Studies of the decay of ^{50}V, described in detail in last year's report, were completed with the positive identification of a gamma ray of 1553.77(6) keV due to ^{50}V decay. The sample of vanadium metal weighed 4250 grams and the total counting time for the final data was 135.5 days using an HPGe detector of >100 cc active volume. Based on an absolute gamma-ray efficiency calibration of the system, the partial half-life for the electron-capture decay of ^{50}V to ^{50}Ti was found to be 1.5(3)x10^{17} yr with a corresponding $\log f_o t$ of 23.4(1). For the beta decay branch of ^{50}V to ^{50}Cr lower limits of $T_{1/2}>4.3\times10^{17}$ yr and $\log f_o>24.0$ were obtained. The result for the e.c. branch disagrees with a theoretical calculation of $T_{1/2}=1.5\times10^{16}$ yr. (D.E. Alburger, E.K. Warburton; J.B. Cumming (Chemistry Dept.))

c. The Decays of ^{50}Ca, ^{50m}Sc, ^{50}Sc, and ^{47}K

The initial motivation for these studies was to make a precision energy determination of the 1554-keV gamma ray from the beta decay of ^{50}Sc to ^{50}Ti to assist in establishing the assignment of the ^{50}V gamma ray described in the previous section. The result for ^{50}Sc was an energy of 1553.768(8) keV, a factor of 25 more accurate than the value 1553.7(2) obtained at BNL in 1970. Since other features of the ^{50}C, ^{50m}Sc, ^{50}Sc, and ^{47}K decay schemes were of interest, a thorough study was undertaken using a triton beam from the 3.5-MV Van de Graaff, targets of ^{48}Ca, and a rabbit target-transfer system (not available in the earlier work). Results included precision energy measurements on a number of gamma rays, better gamma-ray intensity data, several new weak beta-ray branches, sharper limits on certain other beta branches, and some energy level lifetime information. Revised decay schemes were proposed and results were compared with theoretical calculations. (D.E. Alburger and E.K. Warburton)

d. The Decay of ^{180}Ta

During the past two years it was shown elsewhere that naturally occurring ^{180}Ta has a spin-parity of $J^{\pi} = 9^{-}$ and is, in fact, an isomer at an excitation energy of -80 keV above the $T_{1/2}$ = 8.1 hr ground state. The decay of the long-lived ^{180}Ta has not been detected thus far although it can decay by electron

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capture or beta decay to 6^+ excited states in ^{180}Hf or ^{180}W followed by cascades of three low-energy $6^+ \rightarrow 4^+ \rightarrow 2^+ \rightarrow 0^+$ gamma rays. In order to search for this activity a 150 mg sample of Ta_2O_5 enriched to 5% in ^{180}Ta was placed in a well-type high-purity Ge detector of ~100 cc active volume. Preliminary runs were reported last year. In the present work the Ge detector was inserted into a 12 inch x 10 inch NaI(Tl) well-type counter, operated in anticoincidence, which reduced the cosmic-ray background by a factor of about 5 in the regions of interest. The intention is to search for the gamma-ray summing lines from ^{180}Ta decay which should be detectable with very high efficiency. Long runs were under way at the end of the report period, but no positive indication of ^{180}Ta decay had as yet appeared. These e.c. and beta-decay transitions are third-forbidden non-unique and it is of theoretical interest to obtain half-life values, or limits. It is hoped to improve on previous experimental limits by more than a factor of 25. (D.E. Alburger; J.B. Cumming (Chemistry Dept.))

e. Single Beta Decay of ^{48}Ca

Although the double beta decay of ^{48}Ca to ^{48}Ti has been extensively searched for because of the great theoretical interest in whether or not neutrinos are emitted in this process, the single beta decay of ^{48}Ca to ^{48}Sc has not been detected and is also of theoretical interest. Since ^{48}Ca has a spin-parity of $J^\pi = 0^+$ and ^{48}Sc has $J^\pi = 6^+$ in its ground state, the only beta decay branch that might occur to any extent is the one to the 131-keV $J^\pi = 5^+$ first excited state. This would be a 4th forbidden unique beta transition with an end-point energy of 151(7) keV based on the presently known Q-value. The 7-keV uncertainty in the decay energy results in a 35% uncertainty in the half-life for a given theoretical ft value. In order to fix the Q-value more accurately it is planned to measure the Q of the ^{48}Ca(^{3}He,t)^{48}Sc reaction using the QDDD spectrometer. If the results suggest that the $T_{1/2}$ of ^{48}Ca for single beta decay might be measurable, a counting experiment would be planned using the HPGe plus NaI(Tl) detector arrangement described in the ^{180}Ta work. A ^{48}Ca sample of about 10 g would be required. The objective would be to search for the known gamma rays from the decay of 44-hr ^{48}Sc in equilibrium with ^{48}Ca single beta decay by means of gamma-gamma coincidence techniques. A previous lower limit of $T_{1/2} > 2\times10^{16}$ yr for ^{48}Ca single beta decay was obtained elsewhere in a ^{48}Ca-^{48}Sc milking experiment. The proposed measurements may be able to improve on this limit by 2 or more orders of magnitude. (D.E. Alburger, E.K. Warburton, C.E. Thorn; J.B. Cumming (Chemistry Dept.))

3. First Forbidden Beta-Decay in Light Nuclei: ^{16}N and ^{15}C Beta Spectra and Extraction of Matrix Elements from $^{15}C(\beta^-)^{15}N_{g.s.}$

^{16}N and ^{15}C beta spectrum measured by Alburger, Gallmann, and Wilkinson in 1958 were reanalyzed to obtain more accurate branching ratios as well as

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a shape factor for the first-forbidden, non-unique $^{15}C(1/2^+) \rightarrow {}^{15}N(1/2^-)$ decay. For the $^{16}N(\beta^-)$ decay, branching ratios of 27.9(5) and 66.3(6)% to the ground state and 6.13 MeV level of ^{16}O, respectively, were deduced. For the $^{15}C(\beta^-)$ decay, branching ratios of 36.8(8) and 63.2(8)% to the ground state and 5.30 MeV levels of ^{15}N, respectively, were determined. The ^{15}C shape factor was found to deviate significantly from the allowed shape. Analysis of the shape factor results in the determination of the rank 0 component of the transition and determination of the two independent matrix elements which contribute to the rank 1 component. The possible role of muon capture in determining the rank 0 matrix elements was also considered and comparison was made to recent shell-model calculations. The possible meson-exchange contribution to the rank 0 rate has been discussed in last year's FTP. (E.K. Warburton, D.E. Alburger, and D.J. Millener)

F. General Nuclear Spectroscopy

1. Deuteron-Induced Reactions with ^{36}S Targets

Additional data on the $^{36}S(d,p)^{37}S$ reaction were acquired at $E_d = 35$ MeV, using the QDDD spectrometer, for detection angles θ_p of 7°, 10°, 25°, and 50°. These data, in conjunction with the 7 angles measured previously at BNL for $10° \leq \theta_p \leq 50°$, are being fitted with a DWBA analysis to provide an improved set of spectroscopic factors and angular momentum assignments. The Optical Model fit has also been examined to find a better solution set for the scattering parameters.

The $^{36}S(d,^3He)^{35}P$ pickup reaction was first observed previously in this laboratory at $\theta(^3He) = 20°$, $E_d = 30$ MeV. These measurements have been extended to angles of 8°, 15°, 25°, 35° in order to obtain more detailed spectroscopic information for the several states observed in ^{35}P for $E_x < 5$ MeV.

In both of the above cases, the new measurements employed thinner ^{36}S targets in order to achieve better particle resolution. This is particularly important, since much of the structure of ^{37}S and ^{35}P was previously either largely or completely unknown. (C.E. Thorn, E.K. Warburton, J.W. Olness; S. Raman (ORNL))

2. Mass Measurements of Neutron Rich Nuclei Using ^{48}Ca and ^{36}S Targets with a ^{14}C Beam

The high intensity high energy (110 MeV) ^{14}C beam provides a unique opportunity, in conjunction with neutron rich targets such as ^{48}Ca and ^{36}S to reach several new nuclides, and many whose spectroscopy is relatively unknown. One of the most interesting of such nuclides is ^{14}Be. It is the lightest known $T_z = 3$ nucleus, and is predicted to be barely 2n bound, so that a mass determination would

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be important in determining the particle stability of neighboring, unobserved nuclei. The QDDD spectrometer with the 150 cm ion chamber focal plane detector can be used to detect and identify reaction products from ^{48}Ca+^{14}C reactions. The excellent energy resolution of this detector provides clean particle separation so that very small (~10 nb/sr) cross sections can be observed. In an initial experiment, four ^{14}Be events from the ^{48}Ca(^{14}C,^{14}Be) reaction were observed. Additional data will be taken to positively determine the mass excess. The reactions ^{48}Ca(^{14}C,^{15}O)^{47}Ar and ^{48}Ca(^{14}C,^{18}F)^{44}Cl have also been observed, which lead to the previously unknown nuclides ^{47}Ar and ^{44}Cl. (C.E. Thorn, M.J. LeVine; W. Benenson, B. Sherrill, A. Panagiotou, H. Van der Plicht, K. Beard (Mich. State Univ.))

IV. Direct Reactions

A. The General Program

The experimental study of mutual inelastic scattering has been a novel aspect of the direct reaction program. The emphasis here has shifted more toward the theoretical side: what are the limitations of the seemingly accurate quantum mechanical coupled channels model. Experimentally the program has leaned toward the technically more difficult study of transfer reactions with massive heavy ions between well resolved single quantum states of the involved nuclei. Such experiments have been made possible by recent developments in the QDDD detector system. New experimental programs have largely been spurred on by the important theoretical developments in the understanding of barrier penetration dynamics for quantal systems with internal degrees of freedom. Thus the direct reaction group has taken an active part in the MIT sub-barrier fusion program and helped enlarge the scope to encompass inelastic and transfer reactions near the barrier; this type of data tests the theoretical ideas, and, as a unified picture of nuclear structure, direct and compound reactions emerges, quite "global" experiments are invented. The mechanism for massive transfer (or "incomplete fusion") has been addressed by experiments which measure the circular polarization of gamma rays following the transfer reaction. Massive transfer may be seen as an intermediate mechanism between the simple direct collisions and the deep inelastic ones, and it thus plays an important role in a complete picture of the energy loss process; the route from order to chaos. Yet another facet of the barrier dynamics is connected with the occurrence of resonances in collision systems such as ^{24}Mg+^{24}Mg and ^{28}Si+^{28}Si. A rather rich field exists here to be harvested by the BNL tandems which at present are the accelerators which can provide the required variety and intensity of precision beams. Thus the collaborative program on quasi-molecular states (Penn, Yale, ANL, BNL) has been given increased emphasis. A two day international workshop was arranged at BNL on this subject in June of 1983 with about 50 very active and enthusiastic participants.

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B. Elastic and Inelastic Scattering

1. 180° Elastic Scattering of $^{28}Si+^{12}C$ and $^{28}Si+^{16}O$

Both data sets show a gross elastic excitation function that decreases with energy from Rutherford scattering to about 10^{-2} of Rutherford, then is flat for about 25 MeV, and finally drops rapidly below the 10^{-2} level with further increases in energy. Rather strong oscillations of MeV width are superimposed on the described behavior. A quantitative interpretation with coupled channel calculations has proved difficult, as the number of channels that must be included increases rapidly with bombarding energy. Qualitatively the bend down below the 10^{-2} level coincides with estimates of the energy (and partial wave) of the nuclear rainbow; i.e., the energy and partial wave for which the effective potential no longer has an intermediate minimum (pocket). (J. Barrette, P.D. Bond, O. Hansen; P. Braun-Munzinger (SUNY at Stony Brook))

2. Inelastic Scattering of ^{28}Si from ^{60}Ni at 140 MeV

The analysis of the inelastic scattering of ^{28}Si from ^{60}Ni in terms of coupled channels and a modified DWBA approach has been completed and the results have been published in Phys. Rev. C. (P.D. Bond, O. Hansen, C.E. Thorn, M.J. LeVine; P.R. Christensen, S. Pontoppidan, F. Videbaek (Niels Bohr Inst.); Jiang Cheng-Lie (SUNY at Stony Brook))

3. Inelastic Scattering of ^{28}Si from ^{208}Pb at 210 MeV

The analysis of the inelastic scattering of ^{28}Si from ^{208}Pb in terms of (strongly) coupled channels has revealed a sensitivity to the real diffusiveness of the scattering potential, which has been shown to be close to 0.65 fm. It was also found that consistent βR-values for ^{28}Si (1.78 MeV 2_1^+) can be derived for projectiles ranging from mass 4 to mass 208. The first finding is in full agreement with folding and proximity theoretical models; the latter in direct conflict. The work has been published in Phys. Rev. C. (J. Barrette, P.D. Bond, O. Hansen, C.E. Thorn; P.R. Christensen, S. Pontoppidan, F. Videbaek (Niels Bohr Inst.))

4. Inelastic Scattering of ^{28}Si on ^{28}Si at 151 and 180 MeV

This extensive program has been completed experimentally by measuring the 151 MeV angular distributions back to an angle of 75° (lab) using two position sensitive solid state detectors in kinematic coincidence. The analysis of the 151 and 180 MeV data has been merged with the analysis of similar data from ANL at lower energies (120, 112, and 100 MeV) and a modified version of the coupled

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channels code, CHUCK, has been made to handle the many mutual couplings. Progress has been made in describing the elastic data at all energies and in obtaining a local description of the inelastic data at any particular energy. However, a global and consistent description of the entirety of the data does not seem to emerge--as was suspected all along. It is essential to bring in non-direct (compound-like or deep-inelastic collision-like) mechanisms to complete the picture. The analysis continues. (M.J. LeVine, P.D. Bond, O. Hansen, C.E. Thorn; P.R. Christensen, F. Videbaek, S. Pontoppidan (Niels Bohr Inst.); R.R. Betts, et al. (ANL))

5. Excitation Functions of ^{24}Mg+^{24}Mg Inelastic Scattering

The discovery of sharp resonances in this system has been published in Physics Letters and followed up by three more experiments. In the first, it was shown that as these measurements were continued to higher energies, the effect slowly tapered off. In the second, excitation functions of the much weaker transfer reaction channels were measured. The analysis, under way at Argonne, shows that the resonances found in the elastic and inelastic channels also appear in the reaction channels. The third experiment measured angular distributions of elastic and inelastic scattering in fine steps over a well isolated resonance, the final goal being a complete phase shift analysis. Data reduction is under way at ANL. (O. Hansen; R.R. Betts, S. Saini (ANL); S. Sanders (Yale); R. Zurmühle, P. Kutt (U of Penn))

6. Excitation Functions of ^{40}Ca+^{40}Ca and ^{40}Ca+^{44}Ca Inelastic Scattering

The program has expanded to encompass ^{40}Ca+^{48}Ca, ^{44}Ca+^{44}Ca, and ^{44}Ca+^{48}Ca and to cover transfer reactions and evaporation residues, the latter obtained with the mass recoil spectrometer. Analysis at MIT shows that the data are of excellent quality and a first paper on the evaporation residues has been submitted to Physical Review C. It appears that the Ca studies lead to conclusions that are qualitatively similar to those obtained earlier from Ni+Ni, but that in addition it will be possible to provide quite complete data (e.g., transfer) that will test the new barrier penetration models in great detail, in particular the transfer versus inelastic scattering competition (which is not present in the Ni+Ni data). (O. Hansen; R.R. Betts (ANL); R. Ledoux, M. Beckerman, E. Cosman, H. Al-Juwair, C. Ordonnez (MIT))

7. Elastic and Inelastic Excitation Functions of ^{32}S+^{32}S

A method of producing stable ^{32}S targets of ≈10 μg/cm^2 thickness using sputtering was developed by R. Zurmühle and R. McKwean. With these targets it was possible to measure high resolution excitation functions with the

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large area counter kinematic coincidence method. No narrow structures were discovered. The data analysis has been finished at Penn and a publication is under preparation. (O. Hansen; R. Zurmühle, P. Kutt (U of Penn); R.R. Betts, S. Saini (ANL))

C. Transfer Reactions

1. Study of the $\pi h_{9/2} \times \nu j_{15/2}$ and $\pi h_{9/2} \times \nu g_{9/2}$ Multiplet Structure in ^{210}Bi

In last year's FTP, early, very preliminary results were reported from studies of the ^{209}Bi(^{16}O,^{15}Oγ) reaction. The purpose of the experiment was to gain information about states of the $\pi h_{9/2} \times \nu j_{15/2}$ multiplet by use of the high-spin population selectivity available with certain heavy-ion transfer reactions. Strong particle groups with substantial internal structure and which correspond to excitation of members of the well known $\pi h_{9/2} \times \nu g_{7/2}$ and the presumed members of the $\pi h_{9/2} \times \nu j_{15/2}$ multiplets were observed with the QDDD spectrometer. Measurements were made of the gamma rays detected with a Ge detector in coincidence with particle groups detected in the QDDD spectrometer. Several new states of high spin range in excitation energy from 670 keV to about 2.1 MeV, which are apparent from these data. The gamma decay of these states is predominantly to the higher-spin members of the $\pi h_{9/2} \times \nu g_{9/2}$ multiplet. This serves to provide spin estimates for the new states. Improved statistics are required, however, in order to definitely fix the spin values by more accurate branching information. (A. Sunyar, C. Thorn, O. Hansen, P. Bond)

2. ^{14}C Induced Reactions on ^{40}Ca, ^{58,60}Ni, ^{124}Sn, and ^{138}Ba

Proper analysis of this experiment, first reported in last year's FTP, awaited the development of a code to combine inelastic transitions and two-nucleon transfer reactions. The work on this code was completed in Copenhagen and the subsequent analysis of the data is essentially complete. Results show simple agreement with light ion data for (^{14}C,^{13}C) and a complicated interplay between simultaneous and sequential transfer in (^{14}C,^{12}C). A publication is being prepared. (O. Hansen; F. Videbaek, B. Nilsson (Niels Bohr Inst.); E.R. Flynn, J. Peng (LANL))

3. Transfer Reactions with ^{28}Si Beams

The reactions ^{28}Si+^{28}Si (151.25 MeV) and ^{28}Si+^{48}Ca (180 MeV) have been studied with the QDDD spectrometer and the new focal plane detector. The ^{48}Ca+^{28}Si data have been analyzed and show well resolved transitions between single states of the participating nuclei for the ^{29}Si, ^{27}Al, ^{30}Si, ^{26}Mg, and ^{28}Si exit channels. Preliminary DWBA analysis of the ^{27}Al gs-gs transitions indicates good agreement between data and theory. A publication is being prepared. (O. Hansen,

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C.E. Thorn, M.J. LeVine, P.D. Bond; F. Videbaek, P.R. Christensen (Niels Bohr Inst.); G.C. Morrison, S. Hoath (U of Birmingham))

4. Analysis of ^{208}Pb (^{86}Kr,^{87}Kr) ^{207}Pb Results

One neutron pick-up data from the BNL, Niels Bohr, GSI collaboration on ^{86}Kr+^{208}Pb have been analyzed with the DWBA codes SRC and PTOLEMY. The analysis, in contrast to recent results from ANL, shows excellent agreement between DWBA and data. A publication is being submitted. (A.J. Baltz, P.D. Bond, O. Hansen; Jiang Cheng-Lie, F. Videbaek, P.R. Christensen, S. Pontoppidan (Niels Bohr Inst); D. Shüll, Shen Wen-Qing (GSI); H. Freiesleben (Bochum))

5. Dynamics of Massive Transfer Reactions

Incomplete fusion (or massive transfer) reactions are characterized by the emission of one or several fast light particles in the forward direction, originating presumably from the projectile, and the formation of a compound nucleus by fusion of the remaining projectile fragment with the target. A series of experiments was performed involving ^{16}O (110-140 MeV) and ^{14}N (95 MeV) projectiles and ^{93}Nb, ^{144,154}Sm targets. The polarization of the evaporation residues was determined with respect to the reaction normal by measuring the circular polarization of deexcitation γ-rays in coincidence with light charged particles (p,d,t,α) which were detected at angles of $\theta_{lab}=25^\circ$ and 38°. A halo of seven 3 inch x 3 inch NaI detectors was used to enhance events with large γ-ray multiplicities. Good counting statistics were required because of the small analyzing power (A=2%) of the polarimeters. Therefore several hundred million coincidence events were recorded on high-density magnetic tape.

After the analysis of a major portion of the data, the following results have emerged:

> In coincidence with beam velocity α-particles from the ^{16}O+^{144,154}Sm reaction, the polarization is negative with values of between 10% and 30%, depending on the angle of α detection. This implies that the α-particle is deflected away from the beam direction as expected in a breakup fusion model.
>
> For faster than beam velocity α-particles ($E_\alpha \geq 50$ MeV) the polarization changes sign, indicating a negative-angle trajectory as expected for knock-out or fermi-jet mechanisms. This effect is seen in all reactions studied.

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The polarizations measured in coincidence with protons were found to be very small. Protons therefore seem to be emitted with an angular distribution centered near 0° and with no preference for either positive or negative deflection angles.

In coincidence with d and t, all polarization values are consistent with zero. The statistical errors are larger, however, since these particles are produced in smaller abundancy.

It is intended to measure the spectra and anisotropies of coincident discrete γ-ray transitions for selected cases which should aid in the interpretation of the polarization data. (P.D. Bond, O. Hansen, W. Trautmann; W. Hering, R. Ritzka, W. Trombik (U of Munich); H. Tricoire (IPN Orsay))

V. Fusion-Evaporation Reaction Mechanisms: Evaporation Residues from Heavy Compound Nuclei

Low yield evaporation residues from heavy compound nuclei can be identified and studied as individual isotopes only if they are first separated from the ion beam and target recoil particles. This separation at zero degrees and other angles is accomplished electromagnetically with the Recoil Mass Separator (RMS). The recoil compound nuclei or evaporation products are separated by virtue of their unique heavy mass, high charge state, and low velocity. Once separated, they can be identified by their alpha decay and their daughter products, and the corresponding alpha-decay energies and half-lives. The reactions described below result in the heaviest compound nuclei under study at the Tandem Van de Graaff facility and generally required heavy-ion beams of the highest possible energies and intensities.

A. Possible Entrance Channel Effects in the Formation of ^{204}Rn by ^{35}Cl + ^{169}Tm, ^{48}Ti + ^{156}Gd, and ^{65}Cu + ^{139}La

Previous measurements with the RMS have suggested that entrance channel effects in compound nucleus reactions may play a strong role in the formation of different evaporation residues. In order to make a definitive measurement, excitation functions for the evaporation residues from the reactions ^{35}Cl + ^{169}Tm, ^{48}Ti + ^{156}Gd, and ^{65}Cu + ^{139}La, all of which form the compound nucleus ^{204}Rn, were measured. For the more symmetric ^{65}Cu-based reaction, compound nucleus formation at the Coulomb barrier corresponds to a ^{204}Rn excitation energy of 35 MeV, while for the more asymmetric ^{48}Ti + ^{156}Gd and ^{35}Cl + ^{169}Tm reactions, the ^{204}Rn excitation energies are 43 and 52 MeV, respectively. All of the evaporation residues for each reaction were studied over the maximum excitation range available within the energy limits of the upgraded three-stage operation.

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The excitation residue distributions were compared with each other and with the predictions of the evaporation code "OVERLAID ALICE." The qualitative comparisons with the code were remarkably good; however, the prediction of the "cold nucleus" concept was found to be inverted. The cold nucleus concept is that compound systems fused from increasingly more symmetric target and projectiles will have lower excitation at the Coulomb barrier energy and consequently the residue yield will compete more effectively against fission which is the predominant final channel for compound nucleus decay in this region. However, the lower excitation or "colder" compound system is formed at much higher angular momentum than the more asymmetric systems, a factor which is not considered in the simple cold nucleus argument. In these three systems, the residue yield decreased approximately a factor of three as the excitation decreased from 52 to 35 MeV, opposite to the predictions of the cold nucleus concept.

In addition, the first and second moments of the gamma multiplicities associated with the three reactions were measured. The relative moments between reactions were found to be very close to those predicted by ALICE. This work has been submitted for publication. (H. E. Wegner; R. Rohe, A. DiRienzo, H. Enge, M. K. Salomaa, A. Smith (MIT); W. Schier (U. of Lowell); N. Tsoupas (Yale Univ.))

B. Search for Heavy Transuranic Elements

The two reactions $^{37}Cl + ^{232}Th \rightarrow ^{269}107$ and $^{37}Cl + ^{238}U \rightarrow ^{275}109$ were studied with the RMS at energies at and below the Coulomb barrier in an attempt to find some evidence for the formation of transuranic evaporation residues. The signature for such formation would be the detection of residue decay alpha particles with energies well in excess of 6 MeV. No alpha activity with energies > 6 MeV was observed for the $^{37}Cl + ^{232}Th$ reaction at any energy; however, at 185 MeV (approximately 10 MeV below barrier) a few energetic alpha events were observed for the $^{37}Cl + ^{238}U$ reaction. (None were observed at either 180 or 190 MeV.) A total of 11 alpha events ranging in energy from 6.1 to 12 MeV were observed. A 40-hr count with the same detector after the bombardment ended showed 8 more alpha events ranging in energy from 6.7 to 8.8 MeV.

These energetic alpha particles could result from decaying transuranic evaporation residues or from some kind of background as yet unexplained. A follow-up run was made continuing these measurements at higher beam currents by employing a rotating target. Again, energetic alpha particles ranging from 6 to 11 MeV were observed but not with sufficient statistics to form any pronounced spectrum of peaks. The induced residual alpha activity was counted for 6 weeks and showed many alpha events ranging from 6 to 9.5 MeV including peaks at 6.75, 7.6, 7.9, and 9.0 MeV. These alpha energies and lifetimes (months) do not correspond to any known

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decay products that could be the logical end results of ^{275}109 evaporation residue alpha decay chains.

A much improved measurement was made that provided an absolute position measure of each event in a series of three position-sensitive detectors (side by side) as well as x-ray events in coincidence with all alpha events and an absolute time recording of all events. This multiparameter measurement used the new CAMAC capability of the SIGMA-7 computer system and also allowed the sophisticated live measurement system used during bombardment to continue on the residual activity measurements for two months after completion of the live measurement. The position information allowed alpha decay chain determination with single alpha events rather than energy resolved peaks and, in many cases, short lifetime measurements as well.

These data were extensively analyzed at both BNL and MIT; however, it was not possible to identify any kind of alpha decay chain that could conceivably belong to element 109. Although several dozen or more alpha particle events with energies ranging from 7-10 MeV were observed, they were not properly position correlated to form a decay chain without many other lower energy background events in the chain as well. In addition, there were no significant x-ray coincidences above random background counts. The only conclusion at present is that recoil target events from ^{238}U or contaminants are interfering excessively with any transuranic event that may be produced.

Some kind of crude mass analysis is necessary to remove all recoil events of mass $\leq$ 250 so that any events observed for heavier recoils will be free of background. Suitable modifications to the RMS that will provide such resolution are under study. (H. E. Wegner; H. A. Enge, M. Salomaa, R. Ledoux (MIT); W. Schier (U. of Lowell))

VI. Application of Nuclear Techniques to Atoms, Molecules and Materials

A. Solid State Physics

1. Technique: Time-Dependent Perturbed Angular Distribution Measurements

There are several aspects of solid state physics which can be studied very effectively using in-beam Time-Dependent Perturbed Angular Distribution (TDPAD) measurements of gamma rays from nuclear isomers. Among them are: 1) magnetism and paramagnetism of metals and dilute alloys; 2) the behavior of the internal electric field gradient (EFG) in metals; 3) mechanisms of production and annealing of in-beam radiation damage. The technique makes use of the high recoil energy of heavy-ion-induced reaction products for implanting the nuclear probe into

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any given host. The major advantages of this method are: 1) One probes a very small local environment of 100 atoms or less. This is in contrast to other solid state techniques, such as neutron scattering or x-ray analysis, which can only sample regions of greater than 1000 atoms. 2) One can study effects present at temperatures ranging from liquid helium to the melting point of the host. This is in contrast to the Mössbauer or nuclear orientation techniques which, even though they can also sample the local environment, are restricted to low temperatures. 3) The large variety of accelerator beam-target combinations available make it possible to study an almost unlimited variety of host-probe systems. In addition, the process of recoil implantation enables one to produce many exotic, dilute alloys with impurity concentrations starting at <1 ppm which for chemical reasons cannot be made in any other way. Measurements along these lines were first begun at the BNL Tandem in FY 1982-1983 in conjunction with the new program of in-beam measurements of nuclear moments of short-lived isomers. Following is a description of the solid state physics results obtained from the continuation of the nuclear moments program described in Section III.C.2.

2. The Relaxation Rate of Nuclear Alignment of Er in Er Single Crystal

In order to unambiguously evaluate the temperature dependence of the electric field gradient (EFG) in Er, the relaxation rate of the nuclear alignment of ^{154,155}Er isomers recoil implanted into single crystal Er was measured as a function of temperature for $85<T<293$K. The residual nuclei, produced by the ^{121}Sb(^{37}Cl,xn)Er reaction, were allowed to recoil into a crystal of Er oriented so that the c-axis was parallel to the beam direction. In this configuration the nuclear quadrupole hyperfine interaction will not perturb the gamma ray angular distribution and the pure relaxation of the nuclear alignment can be easily measured.

The gamma ray anisotropy is attenuated by a factor $e^{-\lambda t}$ where the paramagnetic relaxation rate, $\lambda = (2\tau_c/\hbar^2)(g\mu_n B_{hf})^2$. This term varies as the square of the nuclear g-factor, and the atomically induced internal magnetic field at the nucleus, B_{hf}. τ_c is the atomic spin flip correlation time which depends on various solid state properties and the temperature. Preliminary analysis of the data indicated a negligible relaxation rate for ^{154}Er and a rate of the order of 100 nsec for ^{155}Er. This reflects the ratio of the g-factors, $g(^{155}\mathrm{Er})/g(^{154}\mathrm{Er}) \sim 5$, as expected. The surprising result, however, was that there was no significant dependence on the temperature. This is in contrast to the expected 1/T temperature dependence as observed for Er in Pb (reported in last year's FTP). Analysis of these results will continue. (M.H. Rafailovich, O.C. Kistner; S. Vajda, G.D. Sprouse (SUNY, Stony Brook))

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

3. Temperature Dependence of the Electric Field Gradient (EFG) in Hg

As part of the program to measure nuclear electric quadrupole moments of the 12^+ isomeric states in the light Hg isotopes, Section III.C.2.e., we have measured the temperature dependence of the EFG in Hg. Recently, several theories have proposed that the temperature dependence of the EFG in s-p metals can be explained in terms of phonon vibration with a 3/2 power of the temperature dependence as given by $\omega=\omega_0(1-B\ T^{3/2})$ where the constant $B=1/M\theta_D{}^2$, θ_D being the host Debye Temperature. Hg provides an interesting test point because the product $M\theta_D{}^2$ is small and the effect is expected to be large. B was found to be $6.7(8)\times10^{-5}/K^{3/2}$. This is in agreement with other published data points and supports the idea that phonon vibrations are the primary source of the temperature dependence of the EFG. (M.H. Rafailovich, O.C. Kistner, A.W. Sunyar; E. Dafni (Weizmann Inst.); S. Vajda, G. Sprouse (SUNY, Stony Brook))

B. Atomic Physics: Measurement of Charge State Distributions of Relativistic ^{197}Au and ^{238}U Ions After Foil Stripping

In support of the heavy ion collider design effort a measurement of charge state yield including fully stripped nuclei of Au and U ions is under way at the Bevalac in collaboration with Harvey Gould. In particular, charge state distributions were measured for 200, 400, 600, 800 MeV/amu ^{197}Au and 200 MeV/amu ^{238}U ions in C, Al, Cu, Ag, and Au foils ranging in thickness from well below to well above the equilibrium thickness. In addition, similar measurements will be made for either ^{139}La or ^{132}Xe in order to provide data in the medium mass region as well.

It is important to know what yield of totally stripped ions can be provided by a synchrotron booster accelerator, currently under design, that will ultimately inject the AGS. Since the yield is dependent on the ion energy and atomic charge of the stripper, the above measurements cover the expected operating range of the booster design and provide the specific data necessary to determine the most optimum design parameters.

Finally, the comparison of the experimental results with calculated predictions is of interest for the electron loss and capture cross section theories in this almost unexplored regime of relativistic heavy ions. (H.E. Wegner, P. Thieberger; H. Gould, LBL))

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

VII. Outside User Program

The Tandem Facility research time is shared approximately equally between BNL scientific staff and the outside user community. Outside user running time is allocated on the basis of recommendations from the Tandem Program Advisory Committee. Membership on this Committee is rotated, new members being chosen with the advice of the Executive Committee of the Tandem Users Discussion Group. The members of the Committee during the fiscal year 1983 were: John Alexander (SUNY, Stony Brook); Benjamin F. Bayman (University of Minnesota); Russell R. Betts (Argonne National Laboratory); James L. Ford, Jr. (Oak Ridge National Laboratory); Lee Grodzins (Massachusetts Institute of Technology); Albert E. Litherland (University of Toronto); Lee L. Riedinger, Jr. (University of Tennessee); Winthrop W. Smith (University of Connecticut); Arthur Schwarzschild (BNL), Chairman; Ottmar C. Kistner (BNL), Secretary and Outside User Liaison).

During the fiscal year 1983 the Committee approved 24 new experiments for running at the BNL Tandem Facility. During this period 23 experiments were completed. The experimental questions addressed cover a broad range of heavy-ion topics—mostly nuclear in nature but with some physics of highly stripped atoms. Experiments based on compound nucleus formation continued to take the largest share of the time (61%). Nearly half of these experiments were directed at studying the dynamics of the fusion process itself. The study of direct reaction processes and atomic physics experiments account for the remaining 16% and 23% of the outside user time, respectively. In all areas, the experiments have entered into new regions of research as made possible by the higher energy beams as well as the highly stripped low energy beams now available on the newly upgraded tandems. It is the latter type of beam made available by the unique 4-stage (accel-decel) mode of operation of the BNL Tandems that accounts for the increase (doubling) of the atomic physics share of time. The MIT-BNL Recoil Mass Spectrometer as well as the QDDD spectrometer are basic to many of the experiments, and the flexible data-taking capability of the continually expanding on-line computer facility is vital to all of them. The Users' Liaison Group supports the outside users so that these capabilities can be employed easily and fully.

A list, by title, of approved experiments completed in FY 1983 follows:

#300. Gamma-ray multiplicities of fission fragments from fusion-fission. S. Steadman, A. Smith, M. Al-Kofahi (MIT).

#324. Gamma-ray studies of trans-lead nuclei. L. Grodzins, P. Boisseau, A. Smith, S. Steadman, J. Wiggins (MIT).

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

#329. High spin spectroscopy for $Z > 82$ neutron deficient transition region: g-factor measurement for Bi and At isomers. D. Fossan, W. F. Piel, Jr., M. Quader, S. Vajda, F. Yang (SUNY, Stony Brook); T. Chapuran (U. of Pennsylvania); E. K. Warburton (BNL).

#331. Beam-foil and beam-gas spectroscopy of Mo, Nb, Zr, Au, and W. J. L. Cecchi (Princeton Univ.); T. H. Kruse (Rutgers Univ.); B. M. Johnson, M. Meron, K. W. Jones (BNL).

#337. Measurement of the E2 collectivity in the strongly deformed nuclei ^{156}Gd and ^{168}Er as a test of collective models. B. Kotlinski, A. Bäcklin, D. Cline, T. Chaki (U. of Rochester); C. J. Lister (BNL).

#339. Transfer reactions with very heavy ions leading to collective final states. M. W. Guidry, C. R. Bingham (U. of Tennesee); C. Baktash, I. Y. Lee, M. P. Fewell (ORNL); D. Cline, A. Bäcklin, B. Kotlinski (U. of Rochester); P. D. Bond (BNL).

#344. Spectroscopy of very light Sn isotopes. I. Grant, B. J. Varley, M. Johnston (U. of Manchester); C. J. Lister (BNL).

#348. Impact parameter dependence of quasi-resonant charge transfer (Parts A and B). S. Hagmann, C. L. Cocke, P. Richard (Kansas State); H. Schmidt-Böcking (Universität Frankfurt); R. Schuch (Universität Heidelberg); B. M. Johnson, K. W. Jones (BNL).

#349. Study of shape coexistence in ^{114}Cd. A. Bäcklin, D. Cline, B. Kotlinski (U. of Rochester); C. J. Lister (BNL).

#351. Formation of ^{204}Rn through three different entrance channels. H. A. Enge, W. Schier, R. Rohe, M. Salomaa (MIT); H. Wegner (BNL).

#354. Nuclear structure of ^{195}Bi via ^{182}W(^{19}F,6nγ)^{195}Bi reaction. D. B. Fossan, T. Lönnroth, W. F. Piel, Jr., M. Quader, S. Vajda (SUNY, Stony Brook); T. Chapuran (U. of Pennsylvania); E. K. Warburton (BNL).

#358. Transfer reactions in Ni-Ni interactions below the barrier. J. Wiggins, L. Grodzins, S. Steadman (MIT).

#361. Near- and sub-barrier fusion of heavy nuclei. M. Beckerman, M. K. Salomaa, J. Wiggins, R. Rohe (MIT).

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

#363. Pre-equilibrium proton emission in heavy-ion fusion reactions. S. Gazes, A. Smith, J. Wiggins, L. Grodzins (MIT).

#364. Limits to angular momentum of evaporation residues. S. Steadman, J. Wiggins, A. Smith, S. Gazes, P. Boisseau, L. Grodzins (MIT).

#365. Fission of ^{56}Ni. R. R. Betts, S. Saini, B. B. Back (ANL); S. J. Sanders, B. Dichter (Yale Univ.).

#366. Search for decoupled bands in doubly odd lutetium isotopes (A=168, 170). A. J. Kreiner, M. A. J. Mariscotti, C. Pomar (CNEA, Argentina); P. Thieberger (BNL).

#370. Identification of ^{182}Tl. K. S. Toth (ORNL); D. Moltz, T. T. Avignone (U. of South Carolina); P. E. Haustein, D. E. Alburger, J. Olness (BNL).

#374. Phase shift analysis of ^{24}Mg + ^{24}Mg and ^{28}Si + ^{28}Si resonances. R. R. Betts (ANL); R. W. Zurmuhle, P. Kutt (U. of Pennsylvania); O. Hansen (BNL); S. J. Sanders (Yale Univ.).

#375. (^{3}He,d) angular distribution studies on ^{26}Mg and ^{27}Al. A. E. Champagne, L. L. Lee, P. H. Zhang (SUNY, Stony Brook); M. J. LeVine (BNL).

#378. Study of the fusion of ^{44}Ca + ^{44}Ca at energies below and above the Coulomb barrier. H. Al-Juwair, R. Ledoux, E. Cosman, M. Beckerman, M. Salomaa and C. Ordonez (MIT).

#380. Development of BNL 4-stage tandem decelerator facility and its use for atomic physics experiments: phase III - quasimolecular x-rays from slow highly charged heavy ion-atom collisions. R. Schuch (Heidelberg); H. Schmidt-Bocking (Frankfurt); I. Tserruya (Weizman Inst.); K. Jones, B. M. Johnson, M. Meron (BNL); J. Barrette (CEN, Saclay).

#385. Gamma-ray studies of sub-barrier fusion. J. Wiggins, M. Beckerman, L. Grodzins, A. Smith (MIT).

Thus far in FY 1984 there are 25 experiments which have been carried over from the previous year or have been newly approved for running. Following is a list of these experiments which are in various stages of completion or preparation.

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

#334. Study of the isotopic dependence of the fusion, elastic, inelastic, and fission-like cross sections for the $^{40}Ca + {}^{40}Ca$, $^{40}Ca + {}^{44}Ca$, and $^{40}Ca + {}^{48}Ca$ systems. R. Ledoux, E. Cosman, M. Beckerman, J. Wiggins, H. Al-Juwair, C. Ordonez, M. Salomaa (MIT); R. Betts (ANL); O. Hansen (BNL).

#367. Correlated electron capture and k-shell excitation in ion-atom collisions. E. M. Bernstein, J. A. Tanis (Western Michigan Univ.); S. M. Shafroth, M. Clark (U. of North Carolina); W. G. Graham (New Univ. of Ulster, N. Ireland); B. Johnson, K. Jones, M. Meron (BNL).

#368. Nuclear structure study using heavy-ion inelastic scattering and transfer reaction. M. W. Guidry, C. R. Bingham (U. of Tennessee); D. Cline, D. Kotlinski, A. Backlin (U. of Rochester); C. Baktash, I. Y. Lee (ORNL); P. D. Bond (BNL).

#369. Search for element 109. H. A. Enge, M. K. Salomaa, W. Schier, R. Rohe (MIT); H. Wegner (BNL).

#371. Search for superdeformed self-conjugate nuclei $^{76}Sr_{38}$ and $^{80}Zr_{40}$. C. J. Lister, W. Gelletly, B. Varley (Univ. of Manchester); H. G. Price (Daresbury Laboratory); J. W. Olness (BNL).

#372. Mass measurements on neutron-rich nuclei using ^{48}Ca and ^{36}Si targets and ^{14}C beam. A. D. Panagiotou, W. Benenson, D. K. Scott, B. Sherrill (MSU); C. Thorn, M. LeVine, P. D. Bond, E. Warburton, J. Olness (BNL); S. Raman (ORNL).

#376. Study of the elastic, inelastic, and transfer reactions in the $^{58}Ni + {}^{58}Ni$ and $^{58}Ni + {}^{64}Ni$ systems. C. Ordonez, R. Ledoux, E. Cosman, M. Beckerman, H. Al-Juwair (MIT); R. Betts, S. Saini (ANL).

#377. Study of the elastic and inelastic scattering of the $^{50}Ti + {}^{50}Ti$ and $^{50}Ti + {}^{46}Ti$ systems. C. Ordonez, R. Ledoux, E. Cosman, H. Al-Juwair (MIT).

#379. Structure in $^{16}O + {}^{16}O$ inelastic reactions at high energies. D. Abriola, P. DeYoung, R. L. McGrath, W. A. Watson (SUNY, Stony Brook).

#381. High spin spectroscopy for neutron deficient Bi nuclei (^{193}Bi). G. Dracoulis, T. Lönnroth, D. B. Fossan, D. M. Lovelock, W. F. Piel, Jr., M. Quader, S. Vajda (SUNY, Stony Brook); T. E. Chapuran (U. of Pennsylvania); E. K. Warburton (BNL).

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

#382. High spin core-coupled states in ^{211}Po and ^{213}Rn. T. Lönnroth, D. B. Fossan, W. F. Piel, Jr., G. Dracoulis (SUNY, Stony Brook); E. K. Warburton, P. Thieberger (BNL).

#383. Very-high spin states in ^{217,218}Rn and their relation to the actinide region collectivity. T. Lönnroth, D. B. Fossan, W. F. Piel, Jr., G. Dracoulis (SUNY, Stony Brook); E. K. Warburton, P. Thieberger (BNL).

#387. Further study of complete fusion of heavy nuclei. M. Beckerman, M. K. Salomaa, J. Wiggins and H. Al-Juwair (MIT).

#388. Study of the $^{25}\mathrm{Mg}(^{3}\mathrm{He},d\gamma)^{26}\mathrm{Al}$ reaction. A. E. Champagne (SUNY, Stony Brook); A. J. Howard, P. D. Parker (Yale Univ.).

#389. Search for doubly decoupled bands in neutron deficient doubly odd Iridium nuclei (A=182,184). A. J. Kreiner, M. A. J. Mariscotti, C. Pomar, D. Abriola (CNEA, Argentina); P. Thieberger (BNL).

#390. Resonances in non-symmetric heavy ion systems. R. R. Betts, S. Saini, S. Sanders, F. Videbaek (ANL), P. Kutt, S. Pate, R. Zurmühle (U. of Pennsylvania); B. Dichter (Yale Univ.); O. Hansen (BNL).

#391. Investigation of critical angular momentum; incomplete and complete fusion of $^{28}\mathrm{Si} + {}^{12}\mathrm{C}$. S. T. Thornton, B. A. Harmon (Univ. of Virginia); D. Shapira, J. Gomez del Campo, J. L. C. Ford, Jr., B. Shivakumar (ORNL).

#392. Mass measurements on neutron-rich nuclei using ^{14}C beam on ^{48}Ca target. A. D. Panagiotou, W. Benenson, B. Sherrill, H. VanderPlicht, K. Beard (MSU); C. Thorn, M. LeVine, P. D. Bond (BNL).

#394. Nuclear structure of ^{26}Ne from the $^{14}\mathrm{C}(^{14}\mathrm{C},2p\gamma)^{26}\mathrm{Ne}$ reaction. R. L. Kozub and students (U. of Tennessee); C. J. Lister (U. of Manchester); J. W. Olness and E. K. Warburton (BNL).

#397. Limits of angular momentum of evaporation residues (II). L. Grodzins, S. Steadman, E. Vulgaris, J. Wiggins (MIT).

#398. Elastic, inelastic and transfer of $^{40}\mathrm{Ca} + {}^{48}\mathrm{Ca}$ at energies below and above the Coulomb barrier. H. Al-Juwair, R. Ledoux, E. Cosman, J. Wiggins, C. Ordonez, R. Brooks (MIT).

#399. Study of the quasielastic and fusion reactions for the $^{16,18}\mathrm{O} + {}^{208}\mathrm{Pb}$ systems at energies below and above the coulomb barrier. E. Vulgaris, R. Ledoux, S. Steadman, H. Al-Juwair, and C. Ordonez. (MIT).

20. Detail Attachments cont.

C. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

#400. Search for superdeformed shapes in ^{154}Er. C. Baktash, I. Y. Lee, Y. Schutz, N. R. Johnson (ORNL); D. G. Sarantites, K. Honkanen, T. Senkow (Washington University); L. L. Riedinger, A. J. Larabee, L. H. Courtney (U. of Tennessee); J. X. Saladin (Univ. of Pittsburgh); O. C. Kistner, A. W. Sunyar, E. der Mateosian, M. Rafailovich (BNL).

#401. Study of the quasiparticle induced shape changes in ^{135}Pr. D. G. Sarantites, K. Honkanen, T. Senkow (Washington University); C. Baktash, I. Y. Lee, Y. Schutz, N. R. Johnson (ORNL); L. L. Riedinger, A. J. Larabee, L. H. Courtney (U. of Tennessee); J. X. Saladin (Univ. of Pittsburgh); O. C. Kistner, A. W. Sunyar, E. der Mateosian, M. Rafailovich (BNL).

#402. Measurement of the sign of the quadrupole moment of the 49/2$^+$ isomer in ^{147}G. E. Dafni, G. Goldring, M. Haas, M. H. Rafailovich (Weizmann Inst.); C. Chasman, O. C. Kistner (BNL).

An important part of the outside user program is the Brookhaven Summer Visitors Program. This program affords invited scientists from other institutions the opportunity to perform experiments at the Tandem in collaboration with BNL scientists while resident at Brookhaven for a period of one month or longer. In addition to the valuable exchange of ideas and experimental techniques, this program can provide an excellent opportunity for prospective outside users to gain experience in carrying out experiments at the BNL Tandem.

A total of 83 scientists representing 28 outside institutions carried out experiments at the Tandem Facility in FY 1983. Their names and affiliations appear below:

D. Abriola (SUNY, Stony Brook)
H. Al-Juwair (MIT)
F. Avignone (U. of South Carolina)
B. Back (ANL)
A. Bäcklin (U. of Rochester)
C. Baktash (ORNL)
K. Beard (MSU)
J. Becker (Livermore)
M. Beckerman (MIT)
W. Benenson (MSU)
G. Bernstein (W. Michigan Univ.)
R. Betts (ANL)
P. Boisseau (MIT)
P. Braun-Munzinger (SUNY, Stony Brook)
R. Brooks (MIT)
C. J. Lister (U. Manchester, U.K.)
T. Lönnroth (U. Jyväskylä, Finland)
M. Lovelock (SUNY, Stony Brook)
J. Lukaisiak (U. Manchester, U.K.)
M. Mariscotti (CNEA, Argentina)
R. McGrath (SUNY, Stony Brook)
D. Moltz (ORNL & U. South Carolina)
T. Morgan (Wesleyan Univ.)
G. Morrison (Birmingham, U.K.)
Y. Niv (Rutgers Univ.)
A. Panagiotou (MSU)
P. Paul (SUNY, Stony Brook)
M. Quadar (SUNY, Stony Brook)
S. Raman (ORNL)
P. Richard (Kansas State Univ.)

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f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

T. Chaki (Univ. of Rochester)
A. Champagne (SUNY, Stony Brook)
P. Christensen (Niels Bohr Inst.)
M. Clark (Univ. North Carolina)
D. Cline (Univ. of Rochester)
L. Cocke (Kansas State Univ.)
E. Cosman (MIT)
E. Dafni (Weizmann Inst., Israel)
B. Dichter (Yale Univ.)
G. Dracoulis (Canberra, Australia)
H. Enge (MIT)
D. Fossan (MIT)
S. Gazes (SUNY, Stony Brook)
G. Goldring (Weizmann Inst., Israel)
W. Graham (New U. Ulster, N. Ireland)
I. Grant (U. Manchester, U.K.)
L. Grodzins (MIT)
M. Guidry (Univ. of Tennessee)
S. Hagmann (Kansas State Univ.)
M. Hass (Weizmann Inst., Israel)
T. Hering (U. Munich, W. Germany)
S. Kelbch (Kansas State Univ.)
B. Kotlinski (Univ. of Rochester)
R. Kozub (Tennessee Tech. Inst.)
A. Kreiner (CNEA, Argentina)
R. Ledoux (MIT)
I. Y. Lee (ORNL)
L. L. Lee (SUNY, Stony Brook)
L. Richen (SUNY, Stony Brook)
R. Ritza (U. Munich, W. Germany)
R. Rohe (MIT)
S. Saini (ANL)
M. Salomaa (MIT)
S. Sanders (Yale Univ.)
W. Schier (MIT)
H. Schmidt-Böcking (U. Frankfurt)
R. Schuch (MPI,Heidelberg,Germany)
D. Scott (MSU)
S. Shafroth (U. Chapel Hill)
B. Sherrill (MSU)
A. Smith (MIT)
G. Sprouse (SUNY, Stony Brook)
S. Steadman (MIT)
J. Tanis (W. Michigan Univ.)
K. Toth (ORNL)
W. Trautman (U. Munich, W. Germany)
S. Vajda (SUNY, Stony Brook)
J. VanderPlicht (MSU)
B. Varley (U. Manchester, U.K.)
B. Varnestig (Univ. of Rochester)
J. Wiggins (MIT)
R. Zurmühle (Univ. of Penn.)
P. Zhang (SUNY, Stony Brook)

FACILITY OPERATIONS

<table>
<tr><td>TITLE
Heavy Ion Facility Operations - Tandem and AGS Transfer</td><td colspan="2">BUDGET AND REPORTING CODE
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04/16/84</td></tr>
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BNL</td><td>WP NUMBER</td><td>TASK NO.</td><td>REV. NO.
0</td></tr>
</table>

20. Detail Attachments.

a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

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b. Publications. -

Baltz, A.J. and Chasman, C. Heavy-ion space charge effects in a magnetic field. Bull. Am. Phys. Soc. 28, 660 (1983).

Chasman, C., editor. Proposal for a 15 A·GeV heavy ion facility at Brookhaven. Informal Report BNL-32250, January 1983.

Chasman, C. and Baltz, A.J. Space charge effects in a heavy ion cyclotron. Nucl. Instr. and Meth. (submitted).

Lindgren, R.A. Brookhaven National Laboratory Tandem Facility. 1983 SNEAP Meeting, Rochester, New York, October 3-5, 1983.

Thieberger, P. The Brookhaven double MP facility. Recent developments and plans for the future. Invited paper presented at the Sixth International Tandem Conference, Chester, England, April 16-23, 1983, and Nucl. Instr. and Meth. (to be published).

Thieberger, P. Possible use of synchrotrons as post-acceleration boosters for Tandems. Presented at the Sixth International Tandem Conference, Chester, England, April 16-23, 1983, and Nucl. Instr. and Meth. (to be published).

Thieberger, P., Barrette, J., Johnson, B.M., Jones, K.W., and Meron, M. Improved four-stage accel-decel production of low energy highly stripped heavy ions. Proc. Seventh Conf. on the Applications of Accelerators in Research and Industry, Denton, Texas, November 8-10, 1982. IEEE Trans. Nucl. Sci. NS-30, No. 2, pp. 1431-3 (1983).

Thieberger, P., McKeown, M., and Wegner, H. Tests for pulsed high current heavy ion synchrotron injection with an MP-Tandem Van de Graaff. Presented at 1983 Particle Accelerator Conference, Santa Fe, New Mexico, March 21-24, 1983. IEEE Trans. Nucl. Sci. NS-30, No. 4, 2746-9 (1983).

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f. Technical Progress.

Technical Progress in FY 1983 and Expected Progress in FY 1984.

I. Tandem Accelerator Performance and Improvements

   A. Accelerator Operations and Performance
   B. Intershield for MP7
   C. ^{14}C Beam Production
   D. High Intensity Beam Tests for AGS Injection

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

- II. Experimental Facilities and Instrumentation
  - A. Computer System Improvements
  - B. QDDD Spectrometer Improvements
  - C. Relativistic Heavy Ion Instrumentation
    - 1. Overview
    - 2. Multi-particle Spectrometer (MPS) Detector System
    - 3. Multi-function Spectrometer (MFS)
      - a. Plastic Ball
      - b. Forward Calorimeter and Z^2 Scintillation Hodoscope
      - c. Charged Particle Arm
      - d. e-γ Arm
- III. Tandem-AGS Transfer Line

I. Tandem Accelerator Performance and Improvements

A. Accelerator Operations and Performance

Both accelerators continued operating with high reliability. During the calendar year 1983, beams (two-stage, three-stage, and four-stage) have been delivered for experiments during 67 percent of the time, while 8 percent was used for scheduled maintenance, development, and conditioning; 3 percent for unscheduled maintenance; and 22 percent for weekend and vacation and other scheduled shutdowns.

B. Intershield for MP7

A "portico" type intershield is being ordered and will be installed in MP7 before the end of FY 1984. This new system was developed for the model MP accelerator at Strasbourg, France, and increased the maximum voltage performance of that machine from 16 to 18 MV. Equal or even higher maximum voltages are expected for MP7, but more significantly, the performance at 16 MV will become more stable and reliable which is of particular importance for the use of this accelerator (alone and in combination with MP6) as a heavy ion collider injector for the AGS.

The "portico intershield" consists of an electrostatic structure connected to the half-voltage column dead sections and equidistant between the tank wall and the high voltage terminal in the center of the accelerator. It reduces the electric field strength at the terminal for a given voltage and also reduces the total amount of stored electrostatic energy.

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

C. ^{14}C Beam Production

A new ion source system was developed for the production and acceleration of intense ^{14}C beams. There are very few such beams available elsewhere and all at much lower energies. Active research programs have been initiated using this unique capability.

The ^{14}C ion source system consists of a Middleton Mark VII high intensity sputter source which has been incorporated into a self-contained system including an ion pump, an einzel-lens, and steering plates. Beam intensities as high as 2.5 μA have been obtained and used in MP7 experiments.

D. High Intensity Beam Tests for AGS Injection

The high current negative hydrogen ion source used to inject the AGS (~200 mA) will be installed on the tandem accelerators in order to determine what maximum pulsed current can be accelerated before excessive tube loading occurs. Previous high current pulsed heavy ion tests did not reach current levels that showed any evidence of limiting. The loading tests with H^- ions is ideal because the current load will be balanced on the low and high energy ends of the machine unlike the heavy ions which load the high energy end in proportion to the stripped charge state distribution.

The AGS ion source will also be tested with various gases other than hydrogen in order to see if it can also produce negative heavy ions, possibly well in excess of that possible with the high current General Ionex source currently in use.

II. Experimental Facilities and Instrumentation

A. Computer System Improvements

The continuing efforts to upgrade and improve the peripheral subsystems of the computer reached the final stages. The tape system was completed with the addition of a fourth high-density, high-speed drive. The mass storage disk system was completed with the addition of a second 300 mbyte Winchester disk drive.

The CAMAC based interface for data collection was improved by the addition of high-resolution analog-to-digital converter interfaces. These interfaces use the same analog-to-digital converters which are in use on the data collection station when CAMAC is not being used. They provide the resolution and linearity required in experiments.

The second CAMAC system was converted to be used in a stand-alone mode of operation for developing sophisticated detectors in the laboratory. This

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

system includes its own graphics display, histogramming memory, fast front-end processor, and mini-computer system. Software which is written during the testing and construction phases of the detectors is used when on-line data is acquired, thus eliminating the time required to debug the software while the experiment is using accelerator beam time.

Software modification and improvements were made to the data analysis programs to accommodate new types of experiments. Programs were written to be able to read experimental tapes written at other facilities. Due to the increasingly larger number of descriptors being collected in experiments, changes were made to allow the collection of multiple spectra during one pass through list-mode data tapes.

The initial design and procurement of components for implementing computer control and monitoring of the transfer line from the Tandem to the AGS was begun. This system will allow the operators to control the magnets and monitor the beam to effect proper transfer.

B. QDDD Spectrometer Improvements

The 150 cm focal plane detector has been modified in several ways to improve its dynamic range, resolution, and ease of use. Field shaping electrodes have been installed around the perimeter of the detector, out of the path of the incident ions, which provide for better collection of charge at the entrance and exit faces of the active volume. This results in better total energy and E_1 resolution, and therefore better particle identification. Electronic noise and energy loss straggling now dominate the energy resolution of the detector.

A plastic scintillator has been mounted along the back of the detector, behind a thin gas window, to stop energetic light ions. It is useful for identifying ions up to ^{12}C, and is essential for Z=1 and Z=2 ions.

The detector has been made easier to use by installing voltage dividing networks to proportion the voltages to the various electrodes in the ion chamber and proportional counter elements. A track has been constructed to move the detector from the focal plane onto a cart so that one person can handle this large detector for window changes and repairs.

Tests have been made of bursting and safe operating pressures for various mylar window thicknesses from 0.1 to 1.0 mil. This data allows for safe operation of the detector with minimum dead layers and therefore best resolution. A manual has been prepared to assist the user in setting up and operating the detector.

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

C. Relativistic Heavy Ion Instrumentation

1. Overview

With the start of construction of the transfer line imminent, a study group has been formed to initiate detailed plans for the instrumentation requirements for the first experiments with heavy ions at the AGS. It is too early to say what the conclusions of the study group will be, but the basis for the discussion remains the same as in our proposal, BNL 32250. The instrumentation presented therein encompasses both the scope of the experimental problems envisaged and consequently the cost and size of the experimental equipment required: although the final instrumentation selected may be different, the purpose and costs will be comparable. Collaborators and outside user groups will play an important role in the selection and the design of the experiments. The instruments tentatively chosen are described below and will require about two years to construct; by the end of FY 1984 it is anticipated that the final decisions will be made.

The apparatus described here is designed to be used for measurements with heavy-ion beams of mass $>^{12}$C and energies of up to 15 A·GeV. This equipment, consisting of two complementary spectrometer systems, is suited to the multi-pronged approach necessary for a first assault on this experimental challenge. The spectrometers are based largely on existing detector systems, thus reducing costs and keeping development programs to about 2 years' duration.

One of these instruments is designed to study global event structure with nearly complete measurement of individual events in a large solid angle detector. The present Multi-particle Spectrometer (MPS) facility, with some additions to its complement of electronic tracking detectors, will be an ideal tool for measuring energy and momentum flow of charged particles and is the instrument of choice for this role.

To complement the MPS, the Multi-function Spectrometer (MFS) uses a large-solid-angle device such as the GSI/Berkeley plastic ball spectrometer for complete coverage of the fragmentation products of the target nucleus, with small-solid-angle spectrometer arms in the forward direction for detailed measurement of charged and neutral production from the central fireball and projectile fragments. The arms of the MFS, however, will select the interesting events via much more narrowly defined hardware triggers, and are thus well suited to this "microscopic" task. In particular, this system of detectors allows for measurement of lepton-pairs, $\gamma\gamma$, and $\pi\pi$ interferometry.

Both spectrometers will be used simultaneously, in separate primary beams on the AGS floor. Both are capable of sustaining the highest anticipated counting rates, and each will incorporate triggering detectors to select events (e.g., head-on collisions).

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

2. Multi-particle Spectrometer (MPS) Detector System

The MPS is an existing facility based on a large magnetic dipole spectrometer instrumented with an array of high precision drift chambers comprising 10,000 wires for tracking charged particles through the magnetic field. In addition to the magnet and tracking chambers, the MPS facility includes a dedicated data acquisition system and on-line computer, rather sophisticated electronics for fast trigger processing, and a complement of Cerenkov counters and scintillation hodoscopes matched to the magnet aperture.

The MPS is proposed for large aperture measurements of multiplicity, angles, and momenta of charged particles. Multi-particle correlations and strange particle production can be studied over essentially the full range of rapidity. Because of the long magnetic path through the spectrometer, a relatively small number of high momentum tracks will exit the downstream end of the magnet, even for very high multiplicity events (slower particles being swept out the sides). Thus specialized detectors of "conventional" segmentation can be used for particle identification and triggering in this kinematic region, which corresponds to fast forward particles from the central fireball and projectile fragmentation products. Neutral strange particles ($K^0, \Lambda, \bar{\Lambda}$) can be reconstructed through their decay products ("vees") in the tracking chambers inside the magnet. A small angle forward calorimeter will be implemented to measure beam-like projectile fragments, principally as a veto in the trigger.

The MPS tracking chambers, as presently configured, are not capable of handling the complexity of high-multiplicity events anticipated in this heavy-ion experiment. The present chambers, which were designed to withstand very high beam rates, have very compact drift cells: the probability of two tracks hitting the same wire is small even at high track densities. The limitation on multiplicity comes from the fact that space points in each chamber module are obtained by projective geometry (crossed wire planes). With this technique the order of ambiguities grows rapidly with increasing number of tracks. A few additional detectors will be introduced to measure unambiguous space points with extremely fine granularity, and give submillimeter resolution in the vertical (non-bending) plane where tracks are efficiently reconstructed as straight lines. This will vastly improve the ability for pattern recognition algorithms to eliminate ambiguities in the standard chambers, and should allow reconstruction of events with upward of 100 charged tracks in the spectrometer.

3. Multi-function Spectrometer (MFS)

The MFS is a two arm spectrometer with one arm used for charged particles and the other for electron and gamma rays. Each of the detector elements has sufficiently fine granularity to be able to handle the large particle

20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

multiplicities expected. A "Plastic Ball" and a Calorimeter will serve to provide the triggers for selecting events in either arm. It is envisioned that this apparatus would be installed in the C1 beam line utilizing the movable platform which is already installed for an existing spectrometer. This would be reequipped as indicated for the charged-particle arm of the MFS.

a. Plastic Ball

This array gives complete coverage for charged particle emission from the target nucleus. It provides angular measurement through its 650 individual plastic scintillator elements, covering the angular range of 40°. It gives particle identification for the slower particles (E_p<210 MeV, E_d<300 MeV) and can provide π^+ identification via pulse shape recognition of the delayed π^+ decay.

b. Forward Calorimeter and Z^2 Scintillator Hodoscope

A hadron calorimeter 1m x 1m covers an angular range of 2.5°. It is preceded by a scintillation hodoscope which gives signals sensitive to the total charge of traversing particles. This array measures the total energy and charge of projectile fragments near 0°. Its primary use will be as a trigger veto to select collisions with small impact parameter. It will also be used to measure the transparency of nuclear collisions by recording the energy carried by projectile fragments in coincidence with multiplicity triggers in the plastic ball.

c. Charged Particle Arm

This spectrometer arm provides high precision measurements of both momentum and angle as well as mass identification of charged particles emitted in the mid-rapidity range. Its acceptance is ≈20 msr. Particle identification will be made by time-of-flight and energy-loss (dE/dx) measurements up to 1.2 GeV/c for π^+, π^-, K^+, K^-, p, $\bar{p}$, and up to 10 GeV/c with the ring imaging Cerenkov counter. $K^0, \Lambda, \bar{\Lambda}$ will be identified via neutral vee reconstruction, with reduced acceptance.

d. e-γ Arm

This non-magnetic spectrometer uses a total absorption detector (shower counter) to measure angles and energies of electrons and photons. It covers the mid-rapidity range, centered at $\theta_{lab} \approx 20^\circ$, with acceptance ≈20°x20°. It is based on a highly segmented shower counter covering an area ≈1 m² with energy resolution $\Delta E/E < 0.15\ (E(GeV))^{-1/2}$.

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20. Detail Attachments cont.

f. Technical Progress cont.

Technical Progress in FY 1983 and Expected Progress in FY 1984 cont.

III. Tandem-AGS Transfer Line

The construction of a beam transfer line between the Brookhaven Tandem Facility and the Brookhaven Alternating Gradient Synchrotron (AGS) will permit the beams of heavy ions initiated with the Tandems to be further accelerated in the AGS to energies of approximately 15 GeV/nucleon. With minimal modification to the present AGS and Tandem, intensities of oxygen beams of 4×10^{10} particles per pulse (ppp) and intensities of sulphur beams of 6×10^{8} ppp can be anticipated. These beams will have center-of-mass energies approximately a factor of 5 greater than those presently available elsewhere in the world.

The tunnel to house the transfer line will be approximately 2020 feet long and 10 feet in diameter. The location and size of the tunnel was determined by the most suitable entry point for the AGS ring (C20 straight section), and the size of magnets and other equipment required for the transfer line while minimizing the number of beam bends and site modifications.

The steel tunnel will be constructed by boring below grade in the area next to the existing Tandem facility and by cut- and fill-methods in the area near the AGS circle. The tunnel will be connected to the existing Tandem Van de Graaff Facility at the east end of the north wall, will bend 90°, and run parallel to the north wall for approximately 800 feet and will bend north to meet the AGS ring with a double bend at the junction. Emergency exits and support buildings are included in the proposed project.

A new kind of continuous strip "getter" pumping system (currently planned for use with LEP at CERN) is being evaluated on a 200 foot length of simulated transport beam line inside of the tandem accelerator room (300 feet long). This system should provide a better vacuum in a smaller diameter and less expensive pipe than the more conventional multiple ion pump system. In addition, the system, after activation, pumps without any electric power. This test will demonstrate whether or not this pumping system will provide the reliability, pumping capability, and operational convenience necessary for the heavy ion transfer line.

During FY 1983 a preliminary design of the tunnel was finalized and beam-optic calculations were performed. Detailed cost estimates were generated for the entire project.

During FY 1984 the final design will be completed and procurement of the beam transport elements as well as construction of the tunnel will be initiated. The construction project is funded as project number 84-5-123. Part of the labor for installation of the transfer beam line and Tandem modifications will be performed by the Heavy Ion Facility operations group.

3.0 Duke University
Triangle Universities Nuclear Laboratory (TUNL) Cyclograaff Accelerator

1. **What new science is being explored by this facility? What scientific opportunities are being exploited?**

Answer: The TUNL facility provides intense beams of light nuclei, polarized projectiles of protons and deuterons from 2 to 16 MeV, and pulsed, polarized neutron beams from 4 to 30 MeV. Precision measurements utilizing these beams increase our knowledge of the nuclear force and our understanding of the origin of this complicated force, including the validity of the underlying symmetry principles. Several different albeit related approaches are being taken toward this end. As will be described below, these goals are being pursued utilizing the TUNL beams in conjunction with the techniques of capture reaction studies, neutron scattering studies, scattering from polarized targets, and high resolution resonance spectroscopy.

The TUNL polarized beams are being utilized in a program of capture reaction studies which employs a series of high resolution NaI and BGO gamma-ray spectrometers designed and constructed to observe the gamma rays emitted when projectiles are captured by the target nuclei. In the recent past, these studies have been directed toward the few-body problem in nuclear physics. The objective of these studies is to exploit the sensitivity of the analyzing power in capture reaction measurements to small amplitudes which are thought to be present in the wave functions of these nuclei in order to investigate unknown aspects of the nuclear interaction in few-body systems. Effects due to charge symmetry violation (CSV), tensor force effects, and many-body features of these systems have been observed.

The neutron polarization group is measuring and interpreting data for analyzing powers, polarization functions, and polarization transfer coefficients. Details about the nucleon-nucleus interaction for light nuclear systems (A<17) and heavier systems are being established. The measurements for the heavier targets are giving new information on specific terms in the interaction potential: the spin-orbit term, the (isospin) symmetry term, the previously undetermined absorptive spin-orbit term, and the poorly determined symmetry spin-orbit term. The question of CSV and the strength of three-body forces is being addressed through precise analyzing-power measurements for n-d scattering and a test for CSV is approached from comparisons of analyzing powers and polarization functions for (p,n) reactions on light nuclei.

A program to obtain and model results for fast-neutron scattering from elements important to the DOE magnetic fusion energy (MFE) program complements the neutron polarization project. The experimental results from this applied science program at TUNL are employed by the polarization group as a constraint in the nuclear model development. However, the cross-section data alone are used to develop nuclear parameters which give a picture, global in interaction energy and in atomic number, for the neutron-nucleus interaction. Here, TUNL is providing new information on the dependence of the parameters in the 10-20 MeV neutron range.

The polarized-target facility, in conjunction with polarized neutron beams, provides unique opportunities for investigating spin-spin effects and for studying fundamental symmetries. The central and tensor terms of the spin-

spin potential in nucleon-nucleus scattering can be studied via total neutron cross-section measurements with transverse and longitudinally polarized neutrons incident on a polarized target. If the neutron and target spins are perpendicular to each other and to the direction of the beam, then the total cross section is also sensitive to a time reversal violating amplitude. Parity violating effects may also be studied using unpolarized neutrons incident on a target polarized along the beam direction.

The TUNL laboratory has a reputation for developing and utilizing high energy resolution beams. Further, it is unique in the development of high-resolution polarized light ion beams. These beams are presently being used in investigations of symmetry breaking processes, such as CSV, by studying very narrow resonances. Precise data from these low energy experiments complement methods at much higher energies in exploring the spectroscopy of nucleon isobar states in nuclei. Other precision studies of transfer reactions using spin-polarized light ions are being used to investigate tensor-force components of the strong force for few nucleon systems.

The study of nuclear resonances with high resolution proton beams allows the exploration of a whole range of nuclear models. Recently, sensitive tests of statistical theories have been performed. The amplitude correlations observed in our statistical studies provide a crucial check on the validity of direct-reaction theory.

Extensive, new high resolution studies of proton elastic scattering and reactions with nonzero spin targets are now in progress. In addition to providing new spectroscopic information, the more intricate spectroscopy possible with nonzero spin targets may provide the key to the utilization of resonance studies in the testing of the limits of fundamental symmetries. Low energy studies of odd-mass targets also connect with intermediate energy physics, providing independent and complementary information on states observed in both regimes, such as the stretched states in ^{28}Si.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

Answer: The TUNL facility consists of two well-equipped accelerators especially developed for precise measurements of the properties of nuclei via reactions induced by light ion and neutron beams. The main facility consists of a model FN tandem electrostatic accelerator (1 to 8 MV) equipped with an array of 6 ion sources which provide negative-ion injection of beams ranging from polarized protons and deuterons to preaccelerated 15 MeV protons or 8 MeV deuterons produced in a cyclotron. The combination of the 6 sources and tandem accelerator provides variable energy unpolarized beams of 2 to 31 MeV protons, 2 to 24 MeV deuterons and alphas, and polarized beams of 2 to 16 MeV protons and deuterons.

A unique feature of the TUNL tandem is the availability of a pulsing system within the polarized ion source which allows for nanosecond-wide pulses of high intensity polarized proton and deuteron beams. The polarized deuteron beams can be used with the polarization-transfer reactions to give an intense pulsed polarized neutron beam in energy range of 4 to 30 MeV. With these beams and the associated experimental equipment, TUNL is an excellent facility for the study of low energy nuclear reactions induced by polarized beams.

The tandem accelerator is equipped with a terminal stabilizer which has reduced beam energy fluctuations when operated in conjunction with a magnetic analyzer system. Energy resolutions of 600 eV are obtained in solid target experiments with polarized and unpolarized beams.

The second accelerator at TUNL is centered around a model KN Van de Graaff and an associated electrostatic analyzer. This constitutes another unique system, superior to any other for performing ultrahigh resolution experiments with 0.5 to 4.0 MeV proton and deuteron beams.

An energy resolution of 110 eV has been obtained with gas targets and resolutions of about 300 eV with thin solid targets. The excellent beam energy resolution provided by this facility has enabled TUNL to carry out by far the most extensive and detailed fundamental studies of proton resonance reactions done anywhere.

3. What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?

Answer:

Devices	Capabilities
1. Lamb shift polarized ion source	1. 240 nA dc beam of H$^+$ and D$^+$ on target; 150 nA in pulsed mode (2 nsec)
2. Two direct extraction negative ion sources	2. DENIS I - 40 microamperes of H$^-$ and D$^-$; low energy spread beam for high resolution studies; DENIS II - 4 microamperes pulsed-(1.5 nsec) unpolarized H$^-$ and D$^-$ beams
3. Lithium exchange source	3. 1000-2000 nA of ^{3}He$^-$ and ^{4}He$^-$
4. Sputter source	4. Several thousand nA of heavy ions. Dedicated to atomic physics studies
5. Three charged particle scattering chambers	5. Precision devices for studying charged particle induced reactions
6. Two anticoincidence shielded 10" x 10" NaI crystals	6. Used to measure high energy gamma rays (10-45 MeV); Excellent resolution--3% at 20 MeV
7. Two massively shielded neutron detectors	7. Path length of 4 and 6 meters; used for neutron time-of-flight measurements
8. Thin-walled target chamber with seven 3" x 3" NaI crystals	8. Used for gamma-ray angular distribution measurements
9. Two anticoincidence shielded 3" x 3" BGO crystals	9. Used to measure gamma-rays (5 to 20 MeV) in high neutron flux background

In addition, the cryogenic polarized target facility, which consists of a helium dilution refrigerator and a superconducting magnet, is capable of cooling bulk samples to temperatures of 10 to 20 mK in a magnetic field of 70 kG. Polarizations of from 10 to 60 % are obtainable for about 20 nuclei. The nuclei are to be bombarded by a beam of polarized neutrons, and asymmetries in total cross sections measured. This system is one of three operational bulk polarized targets in the world (others are in West Germany and the U.S.S.R.).

Data acquisition and analysis at TUNL is supported by VAX 11/780 and VAX 11/750 computers. Acquisiton is via CAMAC and an intelligent branch driver (MBD-11). Transfer rates up to 500 K bytes/sec for multiparameter events and 200 K bytes/wec for single parameter events are supported by the software system XSYS, developed in-house. XSYS was the first VAX-based data acquisition facility to be dveloped at a nuclear laboratory and features of the system have been adapted at a number of other laboratories.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: High Resolution Studies: Amplitude correlations between channels is a basic implication of direct reaction theory but one which has never been checked experimentally until now. The observation of large amplitude correlations in our extensive set of proton resonance data has provided this crucial test and implies some failure of the conventional theory of direct reactions. These results are the subject of a comprehensive review currently nearing completion.

The successful extension of high resolution measurements to nonzero spin targets has provided valuable new spectroscopic information. For example, the spectroscopic factor for the 6- stretched state in 28Si which was determined via resonance excitation can be compared with those observed in intermediate energy inelastic scattering experiments using electrons, protons, or pions.

Resonance spectroscopy of nonzero spin targets provides key information for the use of resonances in tests of fundamental symmetries. One measurement has provided an orbital angular momentum mixing ratio which is crucial to the interpretation of a previous test of time reversal invariance. In addition, the measurement of entrance channel phases and amplitudes has been performed for the first time for an isolated compound nuclear resonance.

Polarized Capture Reactions: The capture group has been developing and applying the techniques of radiative capture during this period and has studied a number of light and medium weight nuclei via the capture of polarized protons, deuterons, and neutrons. A multipole decomposition of our data permits the investigation of electromagnetic strengths in the excitation energy region of these nuclei in which the fundamental dipole and quadrupole modes are known to exist. Detailed information regarding the population and decay of these modes has been obtained and compared to theoretical models. These studies reveal new systematic trends of these fundamental modes of nuclear excitation.

- Polarized capture of neutrons, protons, and deuterons on 1H, 2H, 3H, and 3He has been measured for the first time. For these few-nucleon problems, the polarization observables are extremely sensitive to small components of the ground state wavefunctions which are due, for example, to charge symmetry violation and tensor force effects. The amplification of these effects in our observables is for some cases remarkable: a 2-3% admixture shows up, for example, for deuteron capture on deuterons as a 10-20% observable effect in the measured tensor analyzing power. Precise and detailed information on polarization observables will help define new models for the origin of these effects--for example, the up-down quark mass difference may explain some features of charge symmetry violation, while quark-based models of the nucleon-nucleon force may account for tensor force effects.

Polarized Target Studies: The cryogenically polarized target facility was installed and made operational in the period FY 1981 to FY 1983. The first target consisted of a 2 cm x 5 cm block of aluminum, cooled to 11.5 mK in a magnetic field of 69 KG. This corresponds to a nuclear polarization of 36%, a factor of four better than the best previously reported polarization for a bulk aluminum sample. Experiments with polarized neutron beams are now underway. These are aimed at measuring total neutron cross sections for transverse and longitudinally polarized neutrons. The first result with 14 MeV longitudinally polarized neutrons gave a spin-spin cross section of 22 ± 35 mb (<90 mb to 2 standard deviations). Improvements in beam stabilization are underway so that measurements of asymmetries in the cross sections to about 0.01% accuracy in future experiments with aluminum and niobium are anticipated.

Charged Particle Reactions: Charge symmetry breaking in light nuclei has been examined at TUNL through isospin-forbidden particle decay channels. By combining precision proton decay data with similar neutron and alpha data in an isospin analysis, the isovector and isotensor amplitudes and nucleon isobar contributions to isospin mixing have been determined.

In addition, the first measurements of tensor analyzing power angular distributions for multiparticle transfer reactions have been made. These distributions have revealed the deviation from spherical symmetry of the alpha particle. Furthermore, these data are more sensitive to the two-particle correlations in the target nucleus than previously expected.

Neutron Induced Reactions: For the first time, precise measurements have been made of the analyzing power for elastic and inelastic neutron scattering in the energy range above 10 MeV. Such information is being collected for isotopes ranging across the periodic table and will be combined with cross section data to characterize the spin-orbit term in the nucleon-nucleus interaction. This term is important but is currently poorly determined for neutrons.

In one basic model for describing the nucleon-nucleus interaction, the neutron and proton scattering from the same target is considered to be identical except for isospin and Coulomb effects. With the addition of neutron-nucleus polarization and analyzing power measurements made during the past few years, extensive data sets for the (p,p), (p,p'), (n,n), (n,n'), and (p,n) reactions have become available that can be used to study these effects. Strengths for the isospin terms for the real and imaginary optical model parameters have been determined for nuclei ranging from 9Be to 120Sn In addition, the even more poorly understood isospin spin-orbit terms have been determined for those nuclei. The implications of this work and the extension to other nuclei will be studied over the next two years.

Polarized-neutron scattering from deuterons is essential for testing wavefunctions obtained from model calculations which include the effects of Coulomb terms, charge symmetry violation, and the three-body force. Data for the analyzing power for n-d scattering have now been obtained with sufficient accuracy to observe statistically significant differences between n-d and p-d scattering at both 10 and 14 MeV. Measurements with higher accuracy and at a higher energies are feasible and could be conducted in FY 1985 if theoretical developments warrant the extended accuracy and energy range. New, kinematically complete observations which will detect the outgoing neutrons when a deuteron is broken up by an incident neutron will be attempted this summer.

TUNL scientists are measuring neutron scattering cross sections for elements important to the design of controlled fusion energy sources. Systematic studies have yielded differential cross section data in the 8-17 MeV range for 20 nuclei. Models have been developed for global parametrization of these cross sections. It will be important to continue these unique measurements in the 14-17 MeV energy range.

Accelerator Based Atomic Physics: A new method has been developed for measuring dielectronic recombination cross sections using accelerated, highly charged heavy ions. This method is presently being used at TUNL, at the Brookhaven tandem MP physics facility, and at the Berkeley SuperHILAC. Dielectronic recombination is an important energy loss mechanism in Tokamaks and is of interest to the fusion power program.

Production cross sections have been measured for highly ionized metastable ions which emit x rays and Auger electrons. The unique properties of these ions make them relatively easy to understand theoretically. The results will have possible relevance to x ray LASER development.

Production of intense, kinematically focused, pulsed neutron beams from heavy ion bombardment of hydrogen is being studied. These beams would be possible projectiles for ionization and excitation studies which would be carried out by observing the resulting electrons and x rays.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer:

FY 1981 - FY 1983

1. Cryogenically polarized target facility installed and made operational.
2. Post-acceleration chopper, installed to provide 1.2 nanosecond pulses of deuterons for time-of-flight spectroscopy.
3. New pulsed direct-extraction negative ion source installed on cyclotron.
4. Data acquisition and analysis computer--a VAX 11/750 added.
5. KN Van de Graaff upgraded with installation of stainless steel electrode accelerator tube to permit terminal voltages up to 4 MV.

FY 1984 - FY 1985

1. Develop and install high resolution neutron spectrometer with a 20 meter flight path and improved timing.

2. Develop and install computer control of tandem beam transport magnet system.

3. Develop and install computer control of the KN Van de Graaff high resolution system.

6. For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: TUNL Budget Profiles
(B/A in thousands of dollars)

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Operations					
Low Energy	$ 343	$ 435	$ 510	$ 655	$ 685
In-House Research					
Low Energy	$ 612	$ 776	$ 855	$1,135	$1,185
Basic Energy Sciences	46	83	80	50	55

7. How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: State of North Carolina -- $30,000 during the FY 1981 - FY 1985 period.

8. For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.

Answer: TUNL Staff
(Man Years)

FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
42	44	43	43	46

9. What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?

Answer: Cyclograaff Facility
(Beam Hours for Research)

FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
6800	7200	6600	6700	6700

It is estimated that 7400 beam hours for research per year represents "full" utilization of the facility.

10. For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?

Answer:

Fiscal Year	Started	Continued	Finished
1981	15	14	16
1982	14	12	16
1983	16	11	17
1984	16	10	17
1985	17	10	17

11. What is this facility's user policy?

Answer: The Triangle Universities Nuclear Laboratory (TUNL) is an on-campus facility dedicated to the research of the faculty, postdocs, and graduate students of the three member institutions--Duke University, University of North Carolina, and North Carolina State University. However, TUNL welcomes outside users and encourages collaborations with in-house staff.

12. For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?

Answer: None.

13. What is the mechanism by which specif'c research proposals for experiments at the facility are considered?

Answer: Research projects at TUNL are normally centered around one of the research groups which are composed of TUNL faculty, research associates, and graduate students. Most of these proposals fit into the overall group research project--thus providing coherence and continuity to the research effort, as well as efficiency. In most cases, the project is, in fact, the basis of a Ph.D. dissertation of a TUNL graduate student. The formulation of the project normally begins with discussions between a group faculty member and a graduate student. After preliminary discussions and feasibility studies, the project is presented to the entire group for further discussion and review. Once a plan-of-attack is agreed upon, the appropriate faculty member will present a beam-time request at a full TUNL staff scheduling meeting which occurs approximately once every six weeks. This system provides graduate students with the freedom to design their own experiments while working within the framework of an established program.

14. How many research proposals have been submitted over the past five years, and how many of these have been approved?

Answer: In the last 5 years, 140 proposals were submitted, 85 of which were approved.

15. How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?

Answer:

Fiscal Year	Faculty	Research Associates	Graduate Students
1979	25	8	31
1980	28	8	35
1981	28	8	32
1982	25	8	32
1983	25	8	32

16. How many industrial researchers have utilized the facility over the past five years?

Answer: None.

17. How many researchers from foreign institutions have utilized the facility over the past five years?

Answer:

Fiscal Year	Researchers from Foreign Institutions
1979	6
1980	7
1981	11
1982	9
1983	10

18. How many researchers from other agencies have utilized the facility over the past five years?

Answer: Two.

19. What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: There are many potential future development possibilities for this accelerator facility, but there are currently no approved plans to undertake any of them beyond the activities identified in the FY 1985 budget request. New research instruments and experimental devices will be developed as the physics research program progresses. We intend to give high priority to the exploitation of the facility's unique capabilities.

20. Please provide a copy of the facility's latest annual report.

Answer: A copy of the "Triangle Universities Nuclear Laboratory Annual Report - TUNL XXII" (September 1, 1982 - August 31, 1984) is attached. **(Note: Excerpts from this report follow.)**

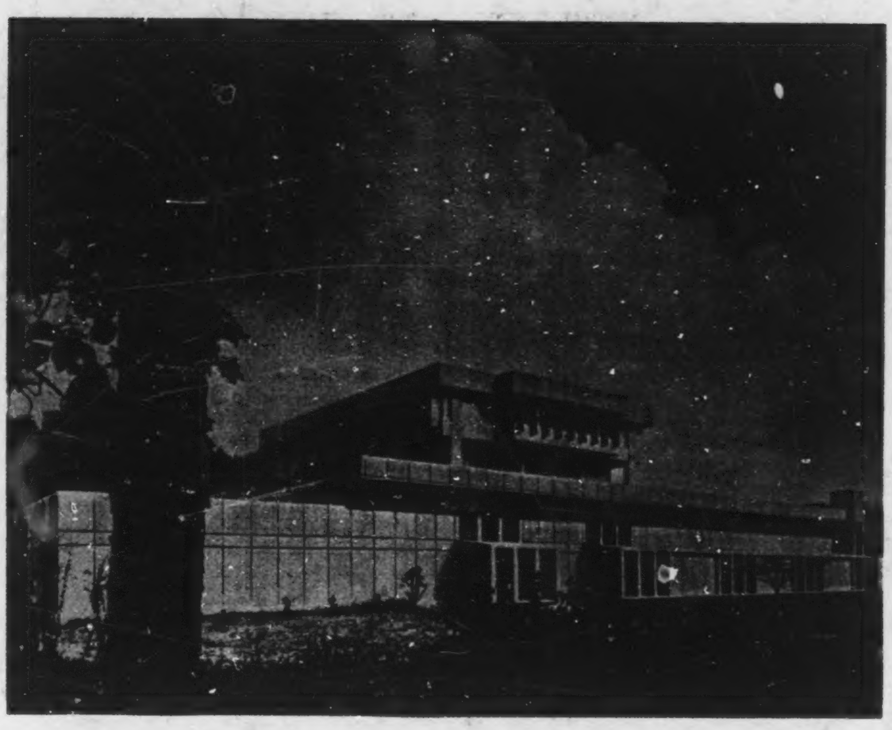
ANNUAL REPORT - TUNL XXII

1 September 1982-31 August 1983

TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

Duke University
University of North Carolina at Chapel Hill
North Carolina State University at Raleigh

Duke Station, Durham, North Carolina 27706



TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

PREFACE

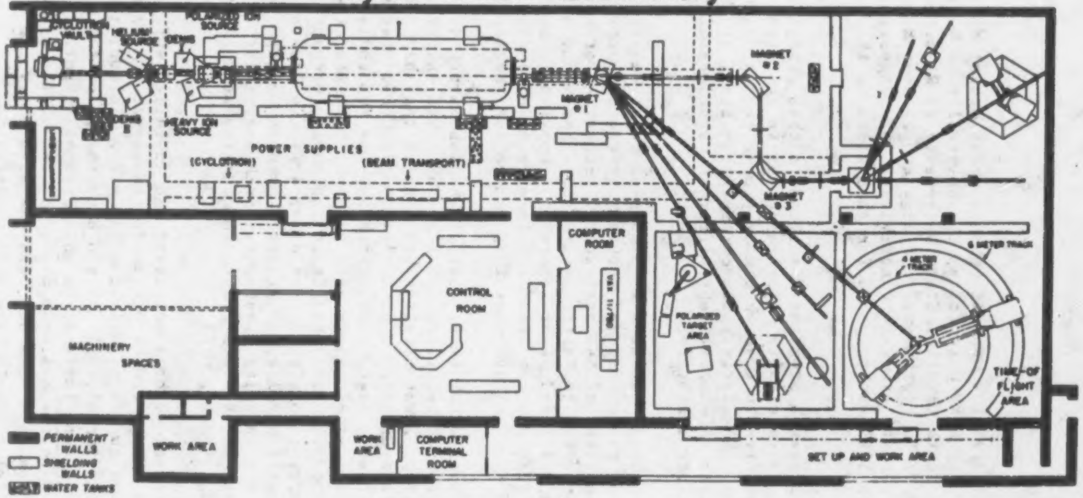
Triangle Universities Nuclear Laboratory is operated as a cooperative research facility by Duke University, the University of North Carolina at Chapel Hill, and North Carolina State University at Raleigh. It is supported by the U. S. Department of Energy and by the three universities. This progress report of laboratory activities for the period 1 September 1982 to 31 August 1983 was prepared for submission to the U. S. Department of Energy.

The varied research programs described in this report reflect a decision by TUNL to devote its major resources to the study of the multiple facets of nuclear structure which can be probed through light-ion induced nuclear reactions. The large permanent research staff at TUNL provides sufficient manpower to exploit many different experimental approaches to questions of nuclear structure.

At TUNL particular emphasis is placed on reactions induced by polarized protons, deuterons, and neutrons. We also continue a major commitment to the study of the statistical properties of nuclear structure revealed by elastic and inelastic scattering experiments using ultra high resolution beams. A third major laboratory commitment involves measurements of fast neutron cross sections required by the Department of Energy's program for the development of controlled thermonuclear fusion.

The major accelerator facilities of the laboratory include a model FN tandem Van de Graaff accelerator and a 15 MeV fixed-energy negative ion cyclotron injector. These accelerators coupled together, constituted the world's first Cyclo-Graaff. A plan view of the Cyclo-Graaff laboratory is shown on the following page. The laboratory has two additional single ended Van de Graaff accelerators with terminal voltages of 4 MV. The upgraded K machine, with its associated equipment, provides intense beams of very high energy resolution. The older 4 MV accelerator, which was the second Van de Graaff accelerator produced by High Voltage Engineering Corporation, is now enjoying renewed research usefulness in a program funded by the National Science Foundation for the study of plant processes utilizing ^{11}C as a tracer.

In the past year we have completed and installed a fast chopper (20 mHz) in the high energy end of our tandem accelerator. With this system we have produced beam bursts of duration < 1 nsec. In addition we have cooled down the cryogenic target to 11 mk and have completed the first two runs with polarized neutrons incident on polarized Al targets. A new direct-extraction source has been placed on top of the cyclotron. We are attempting to bunch this beam and phase it with every 5th cycle of the cyclotron. Initial attempts have been encouraging.



Cyclo-Graaff Laboratory

CYCLOTRON VAULT
HELIUM SOURCE
DEMS
POLARIZED ION SOURCE
DEMS II
HEAVY ION SOURCE
POWER SUPPLIES
(CYCLOTRON)
(BEAM TRANSPORT)
MAGNET #1
MAGNET #2
MAGNET #3
COMPUTER ROOM
VAX 11/780
CONTROL ROOM
POLARIZED TARGET AREA
6 METER TRACK
4 METER TRACK
TIME-OF FLIGHT AREA
MACHINERY SPACES
WORK AREA
WORK AREA
COMPUTER TERMINAL ROOM
SET UP AND WORK AREA
PERMANENT WALLS
SHIELDING WALLS
WATER TANKS

TUNL PERSONNEL

Faculty

Bilpuch, E. G. (director, professor)	Duke
Anderson, R. E. (assistant professor) left 6/83	UNC
Byrd, R. C. (assistant professor)	Duke
Clegg, T. B. (professor)	UNC
Gould, C. R. (professor)	NCSU
Lewis, H. W. (professor)	Duke
Ludwig, E. J. (professor)	UNC
Merzbacher, E. (professor)	UNC
Mitchell, G. E. (professor)	NCSU
Roberson, N. R. (professor)	Duke
Seagondollar, L. W. (professor)	NCSU
Shafroth, S. M. (professor)	UNC
Thompson, W. J. (professor)	UNC
Tilley, D. R. (professor)	NCSU
Walter, R. L. (professor)	Duke
Weller, H. R. (professor)	Duke

Research Staff

Brandt, D. (research associate)	UNC
Dave, J. (research associate)	NCSU
Floyd, C. (research associate) left 3/83	Duke
Guss, P. (research associate) left 12/82	Duke
Karp, B. (research associate)	UNC
Shriner, J. (research associate) left 8/83	Duke
Westerfeldt, C. (research associate)	Duke
Whisnant, S. (research associate) left 7/83	NCSU

Associated Personnel

Biedenharn, L. C. (professor)	Duke
Cotanch, S. (associate professor)	NCSU
Cusson, R. Y. (professor)	Duke
Feres, J. (research scientist)	Texas A and M
Goeschl, J. (associate professor)	Texas A and M
Haase, D. (associate professor)	NCSU
Kalbach, C. (visiting scholar)	Duke
Ludeking, L. (assistant professor)	NCSU
Nelson, C. E. (adjunct assistant professor)	Duke

Park, J. (professor)	NCSU
Rogosa, G. (adjunct professor)	Duke
Waltner, A. W. (professor)	NCSU
Way, K. (adjunct professor) retired 6/83	Duke

Visiting Personnel

Aoki, Y. left 10/82	Tsukuba
Delaroche, J. P. 4/83-5/83	Bruyers-le-Chatel
Del Santo, P. P. 8/82-6/83	Puerto Rico
Santos, F. 9/83-10/83	Lisbon
Ma, Shan-xian	Hefei, Anhui, P.R.C.
Tornow, W. 9/82	Tübingen
Weil, J. 6/83	Kentucky

Graduate students

Adams, G.	NCSU
August, R. A.	Duke
Bowsher, J.	UNC
Brooks, W.	Duke
Burks, B.	UNC
Clark, M.	UNC
Fauber, R.	UNC
Fitzpatrick, C. left 9/82	Duke
Honore, G.	Duke
Howell, C. R.	Duke
King, S.	Duke
McAbee, T.	UNC
Mitev, G.	Duke
Mooney, T.	UNC
Murphy, K.	Duke
Nash, K.	UNC
Nelson, R.	Duke
Pedroni, R.	Duke
Pfutzner, H.	Duke
Ramakrishnan, P.	NCSU
Riley, J.	Duke
Roberts, M.	Duke
Spencer, T.	UNC
Swenson, J.	UNC
Torre, C. left 8/82	UNC
Varner, R.	UNC
Van Hoy, J.	Duke

Wagenaar, D.	Duke
Warthen, B.	Duke
Whitton, M.	Duke
Wilkerson, J. F. left 11/82	UNC
Wright, M. left 6/83	Duke

Temporary Personnel

Adams, J.	5/83-8/83	Duke
Levine, D.	5/83-8/83	UNC
Myers, A.	5/83-8/83	NCSU
Ng, C. Y.	5/83-7/83	UNC
Severns, C.	5/83-7/83	UNC
Smith, J.	5/83-8/83	NCSU
Templon, J.	5/83-8/83	NCSU

Technical Support Staff for TUNL

Bailey, D. M.	Draftswoman
Boyd, M.	Systems Programmer
Carter, E. P.	Accelerator Technician
Edwards, S. E.	Computer Maintenance Supervisor
Gibson, P. M.	TUNL Staff Assistant
Harris, E. P.	Instrument Maker
Hogan, R. G.	Instrument Maker
Lovette, A. W.	Shop Foreman, Instrument Maker
McCrary, P. T.	TUNL Secretary
Mulkey, P.	Electronics Technician
Singkarat, S. left 7/83	IAEA Fellow
Thambidurai, P. left 6/83	Associate in Research
Rummel, R. L.	Accelerator Maintenance Supervisor

A. NEUTRON CROSS SECTION EXPERIMENTS

1. Brief Overview (R. C. Byrd, J. Dave, C. E. Floyd, C. R. Gould, P. P. Guss, G. Honore, C. Howell, K. Murphy, H. Pfutzner, R. Pedroni, S. Singkarat,* L. W. Seagondollar, J. Templon, R. L. Walter, S. Whisnant, J. P. Delaroche**)

Neutron interaction models and cross-section data are significant for basic as well as applied purposes. The neutron program at TUNL has been devised to provide elastic and inelastic scattering data in the 8-17 MeV energy range, a range of importance to the magnetic fusion energy program of the U. S. Department of Energy. Moreover, this energy range is a good region in which to test the energy dependence of direct interaction model parameters as the compound-nucleus contribution for many nuclei is low here. During the past year data for many nuclei have been obtained, some improvements to the measuring system have been implemented, and an important addition, a post-acceleration chopper for the pulsed ion beams, is being developed. Preliminary data obtained with the latter device indicate that it will be possible to reduce the pulse width of the neutron bursts down to 1.2 ns from our usual 1.8-2.0 ns. The first set of cross-section data taken with this new device was obtained at a neutron energy of 17 MeV.

An extension of the global models for the 1p-shell nuclei will be made as our new data for ^{14}N becomes available. New TUNL data at 17 MeV for ^{9}Be will also be incorporated to investigate predictions based on our current model. A phase shift analysis for $^{12}C(n,n)$ from 9 to 12 MeV has been undertaken in cooperation with W. Tornow at Tübingen. Data for Aluminum were obtained from 10-17 MeV to provide a basis for an Al(n,n) optical model. This model will eventually incorporate a spin-spin interaction, the nature of which will depend critically on the size of the effects observed in the TUNL experiments involving the polarized Aluminum target and polarized neutrons. The interpretation of our earlier Silicon data has been enhanced by our new 17-MeV cross-section data; a parallel project for sulfur is also underway. New measurements for ^{40}Ca at 14 and 17 MeV will permit extended coupled-channels tests.

The status of the cross-section results for heavier nuclei is the following. Data sets for $^{54,56}Fe$ and $^{63,65}Cu$ for 8 to

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** Permanent address: Contre d'Etudes de Bruyeres-le-Chatel, France

14 MeV have been transmitted to the National Nuclear Data Center, and similar results for ^{58,60}Ni, ^{116,120}Sn and ^{208}Pb will be mailed shortly. Experiments for ^{89}Y and ^{93}Nb have been completed from 8-17 MeV. Data for ^{58}Ni and ^{54}Fe at 17 MeV have been obtained but are not completely stripped yet.

Phenomenological analyses have been successfully pursued. Deformed optical-model calculations for iron and copper have been submitted for publication, and a paper is under way for ^{58,60}Ni. The ^{116,120}Sn deformed optical-model calculations are completed. Preliminary spherical optical models have been investigated for ^{89}Y, ^{93}Nb and ^{208}Pb.

The analyzing power $A_y(\theta)$ measurements (which complement $\sigma(\theta)$ information) have been proceeding at a constant pace. We now have such polarization data for many of the same nuclei mentioned above at 10 and 14 MeV. The major experimental breakthrough is the capability to obtain moderately high resolution data at 17 MeV, and much of the past year has been spent accumulating high accuracy $A_y(\theta)$ data at this energy. The analyses of the $A_y(\theta)$ data are continuing to lead to surprising results, the latest being a demonstration of the need for a complex ($V_{so} + iW_{so}$) term for nucleon-nucleus scattering at our neutron energies.

The few-nucleon studies, conducted in collaboration with W. Tornow of Tübingen, were confined during the last period to a convincing measurement at 14 MeV which determined that the size of the differences between $A_y(\theta)$ for ^{2}H(n,n)^{2}H and ^{2}H(p,p)^{2}H is smaller than that very recently reported. The new results are now sufficiently accurate to obtain a measure of the (n,n) and (p,p) differences and also to permit a sensitive test for three-nucleon-system calculations.

2. Facility Changes

There have been two major changes in the facility since the last annual report. The first is the installation of a high-energy-beam chopper installed between the high-energy end of the tandem Van de Graaff accelerator and the first beam deflecting magnet. The system is discussed in detail elsewhere in this report (See section H). Use of this chopper has resulted in deuteron pulses on the deuterium gas target of 1.2 to 1.5 ns. These shorter-duration pulses result in higher- resolution time-of-flight spectra that are particularly beneficial in resolving peaks of inelastically scattered neutrons where the neutron emission leaves the residual nucleus in a relatively low-lying excited state.

The second change involves placing additional shadowbar material between the neutron scattering sample and the entrance to the collimators of our two massively-shielded neutron detectors. The purpose of the material (pieces of copper) is to shadow the entrance of the collimator from neutrons that are scattered by air molecules close to the scattering sample being investigated. As reported several years ago, we use massive tungsten shadow bars to drastically attenuate neutrons that could go directly from our neutron production source to the collimator. These bars also attenuate air-scattered neutrons on the near side of the conical region through which neutrons scattered from the sample reach the detector. Now, groups of copper bars are placed to intercept air-scattered neutrons originating from the far side of this region, from below this region, and from above this region. To aid visual alignment of this four-sided shadow system, the double Light Emitting Diode system described two years ago has now been replaced by four LED's located on the top, bottom and each side of the neutron detectors (liquid organic scintillator). Setting up this new four-sided system each time the scattering angle is changed can be time consuming and the time comes out of scheduled accelerator time. It has been determined that the changes in position of the system that are necessary as the detectors are located at new angles can be handled by simply moving the whole assembly of copper along the scatterer-to-detector axis. Special, heavy duty, smoothly moving bases for supporting the copper have been built and installed; the bases roll on "linear ball bearing" assemblies along rigidly mounted guide rods, permitting easy and quick, but accurate, positioning.

3. Studies in the 1p Shell Between 7 and 17 MeV

a. Neutron Scattering Cross Section for ^{16}O between 9 and 15 MeV

This work has been published in Nuclear Science and Engineering, 82 (1982) 393.

b. Cross Sections for ^{14}N and ^{9}Be

Differential cross sections for the elastic scattering of neutrons of incident energies 11, 14, and 17 MeV from ^{14}N and ^{9}Be were measured during the spring of this year. Beryllium nitride was used as a scattering sample, and pure beryllium scattering was measured and subtracted from the beryllium nitride data to obtain the nitrogen scattering data. Typical beryllium, beryllium nitride, and nitrogen difference spectra at neutron energy $E_{lab} = 14$ MeV are shown in Fig. A3-1. The scattered neutrons were observed at angles ranging from 20 to 160 degrees in five degree increments.

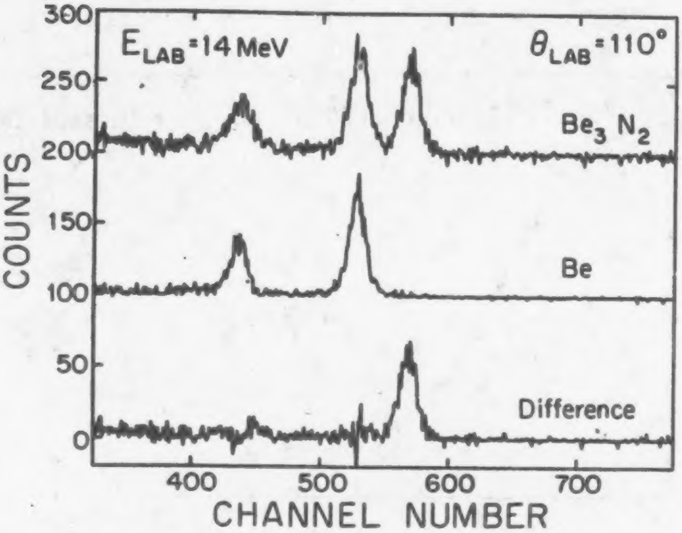

Fig. A3-1. Experimental time-of-flight difference spectra at $\theta_{lab} = 110°$, $E_{lab} = 14$ MeV. The top spectrum is the beryllium nitride spectrum after subtraction of a sample-out spectrum. The middle spectrum is the beryllium data after subtraction of sample-out data. The nitrogen spectrum at bottom is the difference of the above two spectra.

The beryllium data are already in final form and have been processed through the multiple-scattering code EFFIGY. Measurements of both elastic scattering and inelastic scattering to the Q = -2.429 MeV state were obtained. The data at 11 and 14 MeV were used as a check on our previous measurements,[1] and the previously unavailable 17-MeV data have been used in Lane-consistent optical model parameterizations. (See Section B.)

The 11- and 14-MeV nitrogen data have been corrected for finite- geometry and multiple-scattering effects and are in final form; preliminary results have been obtained at 17 MeV. The corrected 11 MeV data are shown in Fig. A3-2 compsred to the previous measurements of Bauer *et al.*[2]

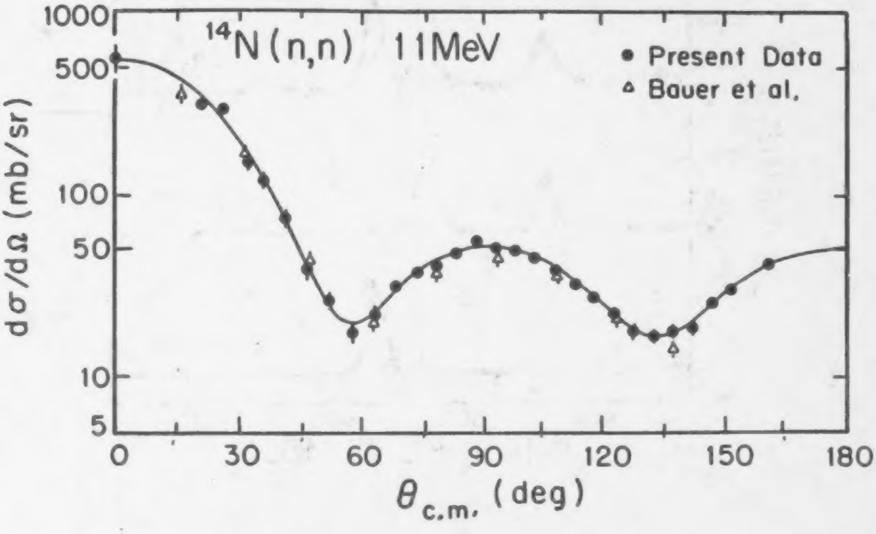

Fig. A3-2. Differential elastic scattering cross section for 11 MeV neutrons on ^{14}N.

After the elastic scattering cross sections are in final form, optical model calcultions will be performed, and an attempt will be made to extract the inelastic scattering cross sections.

REFERENCES (Section A3-b)

1. H. H. Hogue *et al.*, Nucl. Sci. Eng. 68 (1978) 38
2. R. W. Bauer *et al.*, Nucl. Phys. A93 (1967) 673

c. Optical Model Analysis of Scattering of 7- to 15-MeV Neutrons from 1p-Shell Nuclei

This work has been accepted for publication in The Physical Review. The abstract follows:

> "An optical model analysis of results from a program of neutron time-of-flight (TOF) measurements of elastic scattering from the 1p-shell nuclei is described. Experiments have been carried out at the TUNL FN Tandem Van de Graaff facility using the $^{2}H(d,n)^{3}He$ reaction as a neutron source. Experimental methods and past results for neutron scattering from ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C, and ^{16}O are summarized. Data have generally been accumulated at bombarding energies from 7 to 15 MeV in 1-MeV steps, at scattering angles from 25° to 160°. Cross sections are compared to previous work. Much of the neutron scattering data is well described by the spherical optical model (SOM), particularly for nuclei in which resonance structure is not prominent. However, SOM parameters for heavier nuclei do not reproduce the data well. Parameter sets for the individual nuclei are presented along with the results of a global SOM search over 45 neutron scattering angular distributions for all 1p-shell nuclei. Volume integrals for the real and imaginary wells are compared to recent theoretical predictions. The SOM predictions for proton elastic scattering are compared to the available data for the T=0 nuclei. Coulomb correction terms to the real and imaginary potential well depths are investigated."

The final data from these experiments are available upon request from the National Nuclear Data Center and in two cases differ from our previously published results. Improvements in the multiple scattering codes were made after the ^{12}C measurements and the NNDC ^{12}C data set supersedes that originally published in Ref. 1. Also the cross sections and Legendre polynomial coefficients for elastic scattering from ^{11}B are incorrectly interchanged in Ref. 2 for 9.69 and 9.96 MeV. It should be noted that inelastic scattering to the 0.478 MeV state in ^{7}Li was not resolved from elastic scattering in our experiment. For the optical model analysis presented here, an assumed isotropic contribution from this state was subtracted out (see Ref. 3).

REFERENCES (Section A3-c)

1. D. G. Glasgow et al., Nucl. Sci. Eng. 61 (1976) 521
2. S. G. Glendinning et al., Nucl. Sci. Eng. 80 (1982) 256
3. H. H. Hogue et al., Nucl. Sci. Eng. 69 (1979) 22

4. ^{27}Al(n,n)^{27}Al Cross Sections at 11, 14 and 17 MeV

Elastic and inelastic scattering angular distributions have been obtained for ^{27}Al(n,n) at 11, 14 and 17 MeV. Spectra obtained at 70° with the 6-meter detector are shown in Fig. A4-1. The three inelastic groups for which yields were

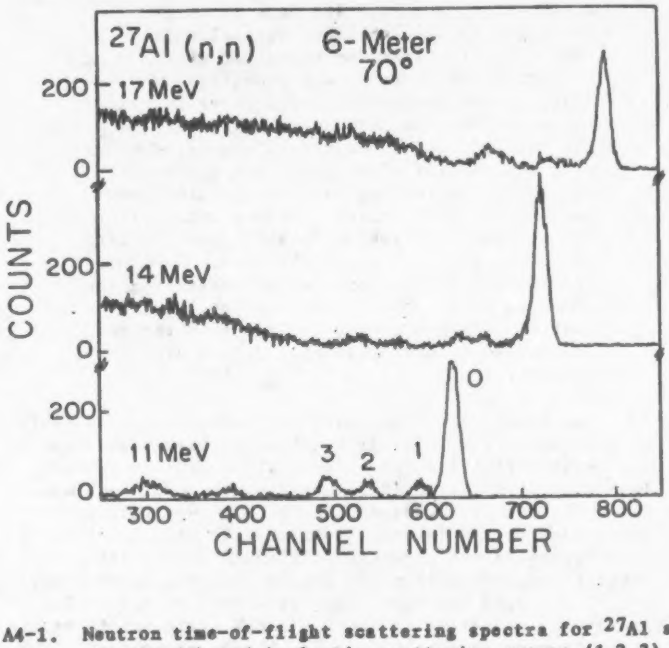

Fig. A4-1. Neutron time-of-flight scattering spectra for ^{27}Al showing elastic (0) and inelastic scattering groups (1,2,3).

obtained are respectively the sum of the 0.84 and 1.01 MeV states, (1) the 2.21 MeV state, (2) and the sum of the 2.73, 2.98 and 3.00 MeV states (3). The angular distributions for 17 MeV are shown in Fig. A4-2. The lines are the results of Legendre polynomial fits to the data. The elastic scattering data have been used to extract optical model parameters. The inelastic scattering data have been successfully fit both via the excited-core and rotation-vibration models. The results are currently being prepared for publication.

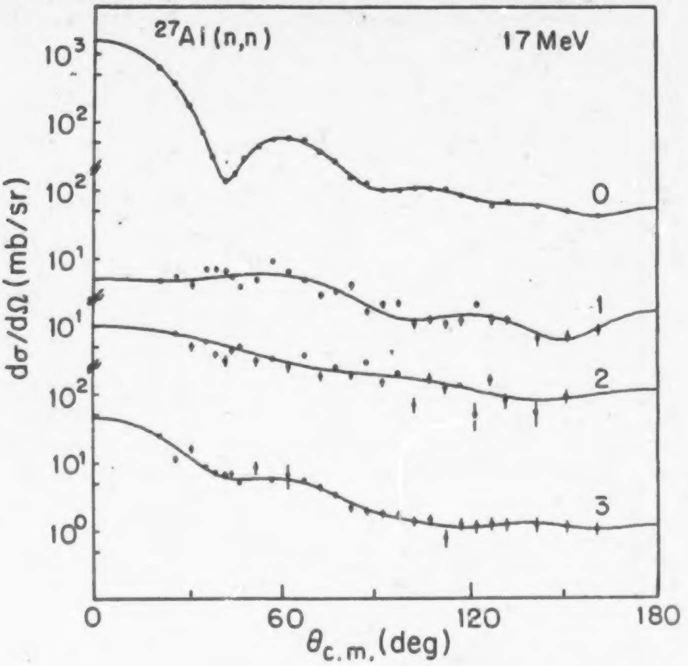

Fig. A4-2. Legendre polynomial fits to the 17 MeV angular distributions for neutron scattering from ^{27}Al.

Neutron Cross Section Experiments

5. ^{28}Si and ^{32}S Cross Sections

Cross-section measurements at 17 MeV have been added to our earlier data at 8, 10, 12 and 14 MeV for ^{28}Si and ^{32}S. Data for the ground state and first excited state have been stripped from the time-of-flight spectra. The results for ^{28}Si are shown in Fig. A5-1.

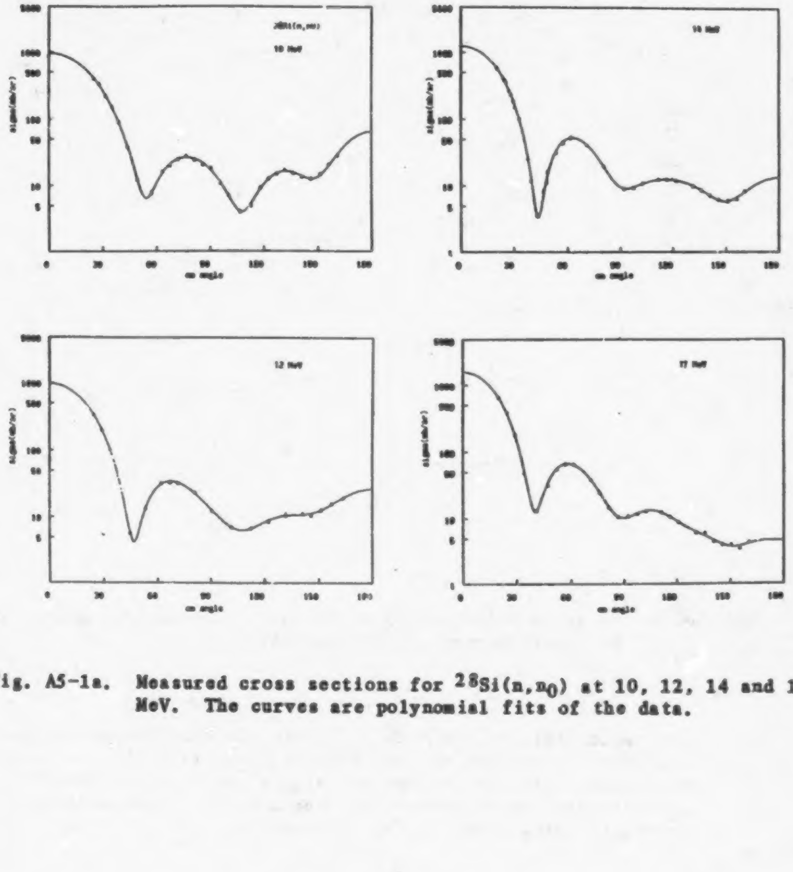

Fig. A5-1a. Measured cross sections for ^{28}Si(n,n$_0$) at 10, 12, 14 and 17 MeV. The curves are polynomial fits of the data.

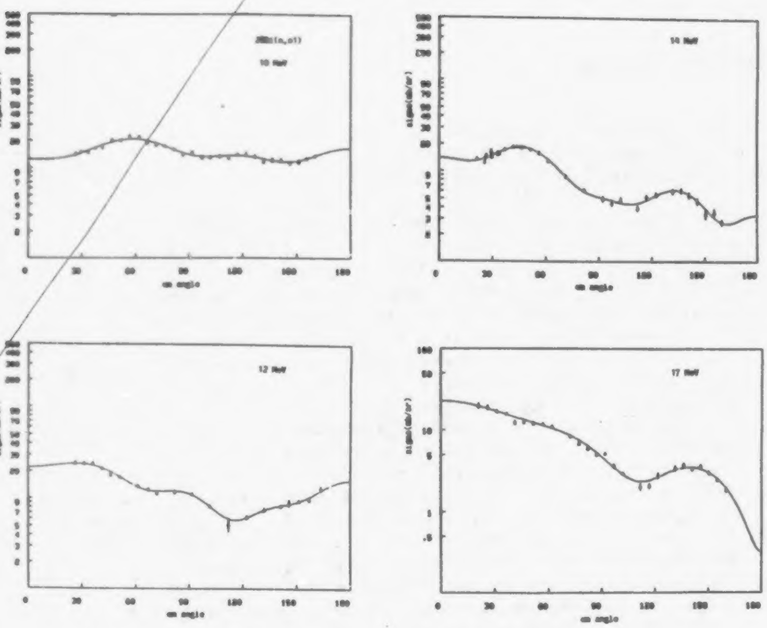

Fig. A5-1b. Measured cross sections for $^{28}Si(n,n_1)$ at 10, 12, 14 and 17 MeV. The curves are polynomial fits of the data.

These data are being used in the coupled-channels (CC) calculations which are expected to describe the $A_y(\theta)$ data from Section B. The goal is to obtain a model with a set of parameters which has a smooth dependence on energy which can be used to predict the $\sigma(\theta)$ for any neutron energy in the range from 8 to about 20 MeV. We will also study the Coulomb correction terms which connect (n,n) models to (p,p) models. The nuclei ^{28}Si and ^{32}S, as well as ^{40}Ca mentioned below, are well-suited for this latter type of investigation as the asymmetry term $\varepsilon = \frac{N-Z}{A}$ is zero for these nuclei.

6. ^{40}Ca Cross Sections

The cross-section measurements for ^{40}Ca(n,n$_0$) at 9.9, 11.9 and 13.9 MeV have been published in Nuclear Physics A385 (1982) 373. The abstract of the paper follows:

> "The analyzing power and differential cross section for elastic neutron scattering from calcium have been measured at 9.9, 11.9 and 13.9 MeV using the ^{2}H(d,n)^{3}He source reaction and neutron time-of-flight (t.o.f.) techniques to detect the scattered neutrons. Polarized neutron beams were produced via the polarization transfer reaction $^2\mathrm{H}(\vec{d},\vec{n})^3\mathrm{He}$ at $\theta = 0°$. The data have been corrected for finite geometry and multiple scattering effects. None of the global neutron-nucleus optical model parameter sets usually referred to in the literature reproduces the present cross-section and analyzing power data. Individual as well as energy-averaged fits of the data resulting from new optical model searches are presented. It is shown that the quoted uncertainties of a recent empirical determination of the real part ΔV_c of the Coulomb correction term are probably underestimated. Our imaginary Coulomb correction term ΔW_c agrees quite well with both a very recent empirical determination and theoretical studies. Although the quality of the fits to the data can be improved by adding ℓ-dependent potentials to the general optical potential no definite conclusions can be drawn from the present data as to whether or not ℓ-dependent potentials are important in neutron-calcium scattering in the energy range investigated. The data have also been analyzed using a Fourier-Bessel series description of the real central optical potential. Comparing the χ^2 values, the experimental data are better reproduced by the Fourier-Bessel method than by our Woods-Saxon optical model analyses. The Fourier-Bessel potentials obtained

> show strong deviations from the standard Woods-Saxon shape but are in good agreement with calculations using the nuclear structure approach."

Measurements at 17 MeV have been made for (n,n_0) and at 14 MeV for (n,n') scattering for the first excited state. These data will complement the earlier analysis and, along with $A_y(\theta)$ data of Section B for $^{40}Ca(n,n')$, will provide the basis for a deformed optical model study.

7. Elastic and Inelastic Scattering from $^{54,56}Fe$ and $^{63,65}Cu$

The data and analyses of the 8 to 14 MeV $\sigma(\theta)$ for the isotopes $^{54,56}Fe$ and $^{63,65}Cu$ have been published in Nuclear Physics. An extension of the analysis which includes $A_y(\theta)$ data has been submitted to Physical Review. In order to make sure that the energy dependences of our models for ^{54}Fe have been properly characterized, we obtained data at 17 MeV. The $\sigma(\theta)$ results have been put into final form and will be incorporated along with the new $A_y(\theta)$ data at 17 MeV in the next stage of nuclear model studies. The 8 to 14 MeV $\sigma(\theta)$ data have been transmitted to the National Nuclear Data Center.

8. $^{58,60}Ni$ Cross Section

Results and analysis of $\sigma(\theta)$ for $^{58,60}Ni$ at 8, 10, 12 and 14 MeV for the ground and first excited states are being prepared for submission to Nuclear Physics. The analysis which involves $A_y(\theta)$ and $^{58,60}Ni(p,p)$ data, considers both a spherical optical model (SOM) and CC optical model. Additional (n,n) cross section data at 17 MeV have been obtained for an extended analysis to follow later.

9. ^{89}Y and ^{93}Nb Cross Sections

Cross-section angular distributions for ^{89}Y and ^{93}Nb have been extended from the earlier set of 8, 10, 12 and 14 MeV to include results at 17 MeV. These data will be analyzed along with $A_y(\theta)$ using the spherical optical model. Some preliminary results suggest the need to include an imaginary spin-orbit term into the SOM for ^{89}Y in order to minimize chi-squared for the fit. Preliminary analysis of the 8 to 14 MeV data for ^{89}Y was shown at the Baltimore meeting and ^{93}Nb at the Amherst meeting.

Neutron Cross Section Experiments

10. ^{116,120}Sn Cross Section

The $\sigma(\theta)$ data for ^{116,120}Sn appeared in the Ph.D. thesis of Paul Guss (abstract appears in Section B). The $\sigma(\theta)$ data set will be complemented by new measurements for ^{120}Sn at 17 MeV. A sample of the CC calculations for elastic and inelastic scattering from Tin were shown in last year's report, and a full description of the CC and SOM models is included in Guss' thesis.

11. ^{208}Pb Cross Section

As reported previously, we have been making SOM and CC calculations for ^{208}Pb from 10 to 17 MeV. Because this nucleus represents a classic case, great care in interpreting the data has been taken. The Mott-Schwinger calculations (and code) have been completed, and a careful study has led to the first evidence for the inclusion of a new spin-orbit term in models for neutron scattering been indicated. The abstract of a Brief Communication to be published in Physical Review follows:

> "The analyzing power $A_y(\theta)$ and differential cross section $\sigma(\theta)$ have been measured for elastic scattering of 10 MeV neutrons from ^{208}Pb. These data were analyzed with a spherical optical model which has a real spin-orbit potential with either a three-parameter conventional form or a one-parameter semi-microscopic form. The predictions with both spin-orbit potentials reproduce the data equally well, suggesting that fewer free parameters can be used in spherical optical model calculations. Including an imaginary spin-orbit term $W_{so}(r)$ in the optical potential greatly improves the fits to the $A_y(\theta)$ measurements and establishes the need for $W_{so}(r) \neq 0$ in the n + ^{208}Pb potential."

The energy dependent SOM analysis which spans 9 to 26 MeV has progressed well and is nearing completion.

12. Monte Carlo Codes EFFIGY and EFFIGYC

The multiple scattering codes for simulating neutron elastic scattering and inelastic scattering to discrete states (EFFIGY) and continuum (EFFIGYC) appear to be in good shape. The code EFFIGY has been exported to the neutron group at Ohio University and continuing interaction with the OU group has led to improved coding and documentation. The code EFFIGYC is quite specialized and is being applied to data previously obtained for scattering 10 MeV neutrons from Si, Cr, Nb, Mo and W. The progress on the continuum analysis has been temporarily stopped as a result of the departure of C. E. Floyd who was handling this project.

13. Neutron Elastic and Inelastic Scattering at Very Forward Angles

(with R. E. Anderson, B. Carp, K. E. Nash)

A preliminary analysis of $\sigma(\theta)$ data obtained in the very-forward angular range from about 1.5 to 9° has been made. Elastic scattering was observed for targets of Pb, Nb, C and Be, and inelastic to the first excited state for C and Be. To obtain the magnitude of $\sigma(\theta)$, the results are normalized to those for Pb. The angular range does not overlap with the region $\theta < 1^\circ$ for which Mott-Schwinger scattering has a large effect on elastic scattering. No results were observed which could not be expected from standard nuclear models. Yet, this is the first "small-angle scattering" results to be processed for inelastic scattering and the first elastic data at small angles for Nb. The Nb data will be included in the analysis disussed in Section A9 above. The size of the effort in the small angle scattering project has been small during the past six months and no more $\sigma(\theta)$ measurements are planned for the immediate future. A progress report was given at the Baltimore meeting.

14. Detector Efficiency Calibration

Data for the relative efficiency of the main (4-meter and 6-meter) time-of-flight detectors were obtained last year using the $^2H(d,n)^3He$ reaction as a calibrated source of neutrons (employing the evaluation of M. Drosg). For the high-energy region (9 MeV $< E_n <$ 18 MeV) an excitation function at 0° was measured in 200 keV steps for several simultaneous biases. For 2 MeV $< E_n <$ 9 MeV, an angular distribution with E_d = 6 MeV was obtained. A sample of the relative efficiency function for two biases (1 x Cs and 2 x Cs Compton edge) is shown in Fig. A14-1. It is hoped to compare these measured values to calculations with the efficiency code of G. Dietze of the PTB lab at Braunschweig, West Germany.

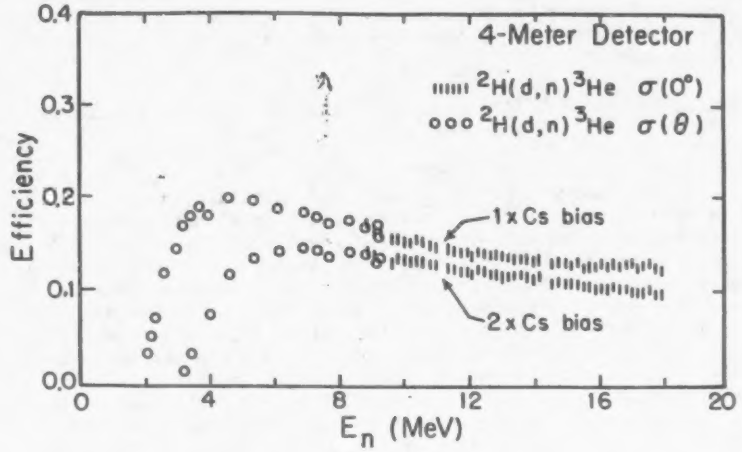

Fig. A14-1. Efficiency curves for biases of 1x and 2x the pulse-height for the ^{137}Cs Compton edge.

15. Calculation of Spin-Spin Observables (T. L. McAbee, W. J. Thompson)

As theoretical support for measurements using the cryogenic polarized target we have been calculating several relevant observables. We have obtained from Dr. H. S. Sherif a copy of SPINSOR[1] to use in analysis and study of the spin-spin interaction. SPINSOR is a distorted- wave Born approximation code for the elastic scattering of nucleons which includes a perturbation calculation of the amplitudes due to scattering from a spin-spin interaction potential. We have tested the code against published calculations for spin-spin dependent observables. Also, we have compared results of usual optical model calculations (e.g., no spin-spin interaction) with those of another code OPTICS[2] and found excellent agreement.

The following changes have been made in the code:

1) We have adopted the use of unit-magnitude spin operators for the spin-spin interaction.
2) We have incorporated expressions for the spin-spin cross section in both the parallel and perpendicular geometries. We modified the code to allow evaluation of zero degree scattering amplitudes for neutron scattering since the spin-spin cross section is obtained through use of the optical theorem.
3) We have made major additions to the documentation of the code to assist users of the code at TUNL.

Additionally, several smaller codes have been developed, or are in development that relate to this work. Chief among those is a microscopic calculation of the central spin-spin form-factor from an effective nucleon- nucleon interaction potential. This follows the technique of[3] and is planned to be incorporated into SPINSOR as an option for the spin-spin form factor.

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1. A. H. Hussein and H. S. Sherif, Phys. Rev. C8 (1973) 518
2. R. J. Eastgate, W. J. Thompson and R. A. Hardekopf, Com. Phys. Comm. 5 (1973) 69
3. Kanetada Nagamine, Akira Uchida, and Shinsaku Kobayashi, Nuc. Phys. A145 (1970) 203

B. NEUTRON POLARIZATION STUDIES

1. Overview (R. C. Byrd, J. P. Delaroche,+ C. E. Floyd,* P. P. Guss,** G. M. Honore, C. R. Howell, K. Murphy, R. S. Pedroni, H. Pfutzner, M. Roberts, W. Tornow,*** R. L. Walter)

Intimately tied to the usual neutron interaction cross sections $\sigma(\theta)$ are cross sections measured with incident polarized nucleons. The observables of this type that we have been interested in measuring are various analyzing powers $A_y(\theta)$ and the cross sections for polarized neutrons through polarized targets. Some of the $A_y(\theta)$ data have been obtained for $(\vec{p},n)$ reactions, but most have been for $(\vec{n},n)$. In the latter case pulsed polarized neutrons are generated through the $^2H(\vec{d},\vec{n})^3He$ reaction at 0°, the reaction having been initiated with pulsed polarized deuterons. Time-of-flight techniques are used to measure both ground-state reactions as well as low-lying excited state ones. The polarized target experiments which have just been initiated use the same nuclear reaction source of pulsed polarized neutrons.

Since the last report, new analyzing powers have been obtained for ^2H, ^9Be, ^{12}C, ^{28}Si, ^{32}S, ^{40}Ca, ^{54}Fe, ^{58}Ni, ^{89}Y, ^{93}Nb and ^{120}Sn. For all these targets except ^2H we have measured the complementary differential cross sections $\sigma(\theta)$. Much of the new data have been obtained at 17 MeV, our highest practical energy attainable at TUNL with the $^2H(\vec{d},\vec{n})^3He$ reaction. We have also made the decision to obtain these data with the two TOF detectors at full flight path (4m and 6m) instead of the reduced path lengths used in our earlier data at 8 to 14 MeV. Use of the second shadow bar (Section A2) has greatly improved the cleanness of our TOF spectra and our ability to measure $A_y(\theta)$ for $(\vec{n},n')$, the only such measurements ever conducted for medium-weight and heavy nuclei.

+ On leave from Service de Physique Neutronique et Nucleaire, Centre d'Etudes de Bruyeres-le-Chatel, France

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*** On leave from the University of Tübingen, Tübingen, West Germany

Analysis of the $A_y(\theta)$ data is leading to a better understanding of the spin-orbit interaction for the spherical as well as the deformed optical potentials. Our Lane-consistent analysis of (n,n), (p,p) and (p,n) data is expected to give information on the isospin spin-orbit term, whereas the polarized target experiments will place limits on the spin-spin term. Our recent finding of the need for a W_{so} term (see Sections A11 and B6) for neutron-nucleus scattering has introduced a complication into our analyses and caused a delay in the publishing of full reports of our studies. The global SOM code GENOA has now been modified to permit this term to have a geometry-independent of V_{so}; this feature is important for obtaining the best fits to the $A_y(\theta)$ data (see Section A11). In another of our projects the Mott-Schwinger interaction which was incorporated into GENOA (in the Born Approximation) has been tested through an "exact" calculation using an optical model code written at TUNL in collaboration with R. Seyler of Ohio State, specifically for this purpose.

Multiple-scattering corrections to the data are important in the region of large $A_y(\theta)$ values and also near the minima in $\sigma(\theta)$. For determining these corrections, the code JANE is employed. The documentation for this code has been improved and tests in the first $\sigma(\theta)$ minimum for ^{28}Si(n,n) were made by measuring $A_y(\theta)$ in about 2° steps for two different source-to-scatterer geometries. The code JANE is also being employed to analyze an independent data set for ^{12}C(n,n) in collaboration with Prof. Weil of Kentucky.

2. Scattering of Polarized Neutrons from Deuterons

To complement our findings at 10 MeV, new data were obtained at 14 MeV for ^{2}H($\vec{n}$,n) scattering. This work was done in collaboration with W. Tornow of Tübingen. The results were accurate enough to supersede most of the earlier 14 MeV data, some of which is believed by us to have underestimated uncertainties. Our new data are sufficiently accurate to provide a test of the most recent three-nucleon calculations. Also, by comparing our ^{2}H($\vec{n}$,n) data to Zurich ^{2}H($\vec{p}$,p) data, we are able to show that the Coulomb effects have yet to be handled properly in calculations for this simple and fundamental scattering system. Until we can have better confidence in the calculations, it is premature to claim that our measurement, when compared to the charge symmetric ^{2}H(p,p) case, gives evidence for the need for a nuclear charge-symmetry breaking term. The results of this work are shown here in Figs. B2-1 and B2-2.

Neutron Polarization Studies

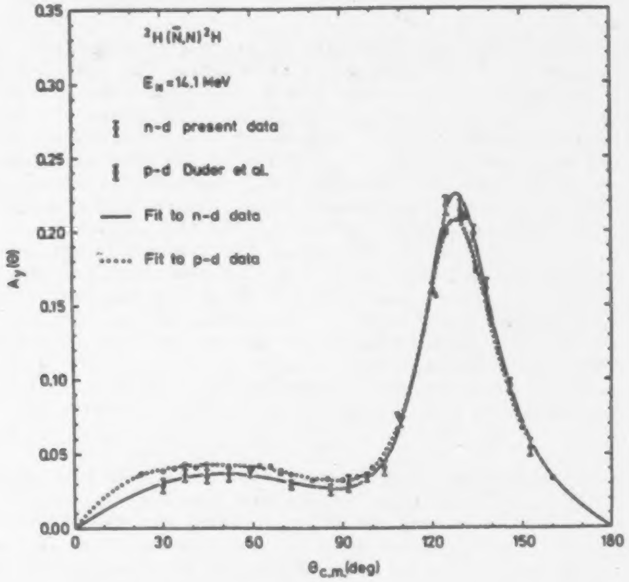

Fig. B2-1. Present neutron-deuteron analyzing power data compared with previous proton-deuteron data.

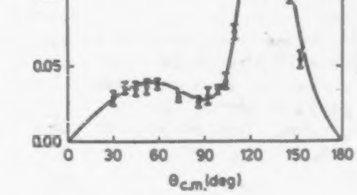

Fig. B2-2. Neutron-deuteron analyzing power compared to Faddeev calculations performed by Doleschall at 14.1 MeV.

These 14-MeV results have appeared as a Rapid Communication in Physical Review 49 (1982) 312. The abstract follows.

> "Data for the analyzing power $A_y(\theta)$ for elastic scattering of neutrons from deuterons have been measured at 14.1 MeV for the range from 30° to 153° (c.m.) to accuracies between ±0.03 and ±0.006. The results are compared to previous n-d data at 14 MeV and are in significant disagreement with the most recent measurement. The present data are in excellent agreement with a Faddeev calculation by Doleschall. The data are also very similar to p-d scattering data at 14.1 MeV, although systematic deviations are observed at forward angles and near the maximum of $A_y(\theta)$ at 130°. Recent calculations indicate that Coulomb effects can explain most of these differences, although some features will require further investigation."

3. Scattering of Polarized Neutrons from ^{12}C

A paper entitled "The Analyzing Power for $^{12}C(n,n_{0,1})^{12}C$ between 8.9 and 14.9 MeV Neutron Energy" has been published in Nuclear Physics A394 (1983) 139. Additional data for $A_y(\theta)$ for $^{12}C(n,n)$ have now been obtained at 6 angles in about 200 keV steps from 9 to 12 MeV. These complement the complete angular distributions measured at TUNL at 9, 10, 11 and 12 MeV given in the above publication. The $A_y(\theta)$ data set is being used along with available $\sigma(\theta)$ data to extend a lower energy phase shift analysis up to 12 MeV. Satisfactory descriptions of the data are being achieved and the results are being checked for ambiguities before the levels of ^{13}C found here will be reported. W. Tornow of Tübingen has assumed prime responsibility for this analysis.

4. The Analyzing Power $A_y(\theta)$ for $^9Be(n,n)$, $^{10}B(n,n)$ and $^{11}B(n,n)$

(K. Murphy, R. C. Byrd, C. E. Floyd, R. L. Walter)

A publication is being prepared based on the analyzing powers measured for $^9Be(\vec{n},n)$ scattering to the ground state and 2.43-MeV state. Very recently we have added a measurement of $A_y(\theta)$ at 17 MeV to the data set. The available cross-section measurements have been reviewed. It is anticipated that spherical and coupled-channels analyses of $\sigma(\theta)$ and these $A_y(\theta)$ results will be submitted for publication in early Fall. This preliminary study will be complemented by a new (n,n), (p,p) and (p,n) Lane-model analysis for ^9Be + N.

We have made $\sigma(\theta)$ measurements for $^{10}B(n,n)$ and $^{11}B(n,n)$ at 15 and 17 MeV which are presently being corrected for multiple-scattering effects. These results will then be used to construct the libraries needed to correct similarly the analyzing-power data that we obtained at 10 and 15 MeV. The measurements of $A_y(\theta)$ for ^{10}B and ^{11}B at 10 and 15 MeV will be employed in our on-going Lane model analyses for 1-p shell nuclei. After the full ^9Be Lane-model study is completed, work on interpreting these Boron data will begin.

5. Scattering of Polarized Neutrons from Medium-Weight Nuclei

The CC analysis of ^{54}Fe and ^{65}Cu $A_y(\theta)$ and $\sigma(\theta)$ data has been submitted to Physical Review C. The abstract follows:

> "Angular distributions of the analyzing power $A_y(\theta)$ have been measured for elastic scattering of neutrons from ^{54}Fe and ^{65}Cu at 10 and 14 MeV and for inelastic scattering from the first 2^+ state of ^{54}Fe at 10 MeV. We have combined the results with previous measurements and analyses of the differential cross sections in the same energy range and have carried out new deformed optical model calculations where the major concern was to study the spin-orbit interaction. The need for an imaginary spin-orbit term $W_{so}(r)$ is discussed. The (n,n') data are important in reducing an ambiguity found between the deformation β_{so} of the real spin-orbit potential and the strength W_{so} of the imaginary spin-orbit potential."

Analysis of the TUNL $\sigma(\theta)$ and $A_y(\theta)$ data for ^{58}Ni and ^{60}Ni between 8 and 14 MeV has been described in the Ph.D. thesis of P. Guss. A portion of the abstract follows:

> "The neutron scattering differential cross sections and analyzing powers have been measured for $^{58,60}Ni$ and $^{116,120}Sn$ at several energies in the energy region 8-17 MeV. These data have been analyzed using coupled channels models, employing the SPRT method of analysis. The quadrupole deformation parameters have been deduced for both the present (n,n') and prior (p,p') measurements. These deformation parameters are shown to coincide with the interpretation by Madsen and Brown of core polarization phenomena. Further, the $A_y(\theta)$ data for the present (n,n') measurements are instrumental in determining the nature of the

spin-orbit interaction, providing heretofore unrealized insights into the nuclear structure of proton-closed-shell nuclei. Not only is it seen that the full Thomas form of the deformed spin-orbit potential is required to describe the data, but it is shown that simple isospin-symmetric arguments which explain the proton scattering by neutron-closed-shell nuclei are not sufficient to explain the data presented here.

Complete spherical optical model analyses have also been performed for the present elastic scattering data. The results of these analyses are seen to be consistent with data previously reported for these elements in their natural abundances. The results of these spherical optical model analyses, and their connection to the coupled channels work, are explained in detail. The spherical optical model analyses for nickel and tin have been combined and extended to obtain a global spherical optical model for neutron scattering which is representative of a far broader mass and energy range than that of the present experiment. The results of the present global model are compared to the landmark works of others in this area. Finally, the results of both the coupled channels and spherical optical model analyses are summarized in terms of per nucleon volume integrals and root-mean-square radii."

The CC and SOM analyses are being drafted for publication. A brief publication on the size of the deformation of the spin-orbit potential for ^{58,60}Ni appeared in Physical Review 25 (1982) 2854. Additional measurements of $\sigma(\theta)$ and $A_y(\theta)$ at 17 MeV which are underway will be used to provide a critical test of the above Nickel models of Guss *et al*.

Measurements of $A_y(\theta)$ for ^{28}Si and ^{32}S have been completed at 10, 14 and 17 MeV for the ground and first-excited states. The statistical model code HAUSER of F. Mann from Hanford has been adapted to the VAX and modified to permit compound-nucleus calculations for $\sigma(\theta)$. The code has been applied to the case of n + ^{28}Si, and will be used for n + ^{32}S in the near future; the CN contributions to $\sigma(\theta)$ and the corresponding effects on $A_y(\theta)$ are large below 12 MeV and are still important at 14 MeV. The data are compared to CN + direct reaction calculations, enabling us to determine the model parameters for n + ^{28}Si reactions. In Fig. B5-1 a sample of the CC (rotational model) calculations is shown. The quality of the data for ^{32}S is similar to that shown for ^{28}Si, but the model calculations have not been initiated yet.

Data have been obtained for $\sigma(\theta)$ from 8 to 17 MeV and for $A_y(\theta)$ at 10 and 14 MeV for the ground state reactions ^{89}Y(n,n) and ^{93}Nb(n,n). We are presently measuring $A_y(\theta)$ for both nuclei at 17 MeV. Preliminary spherical optical model analyses of the 8-14 MeV data have been pursued, but additional work will await completion of the 17-MeV measurements and data reduction.

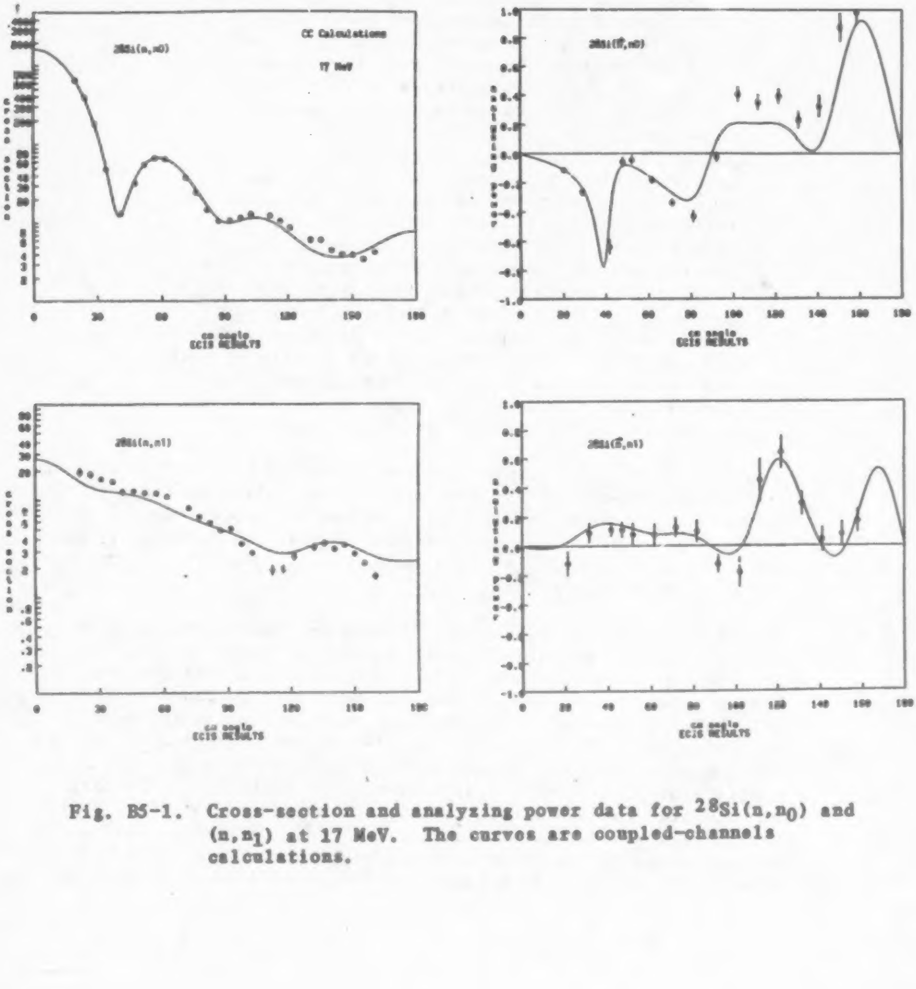

Fig. B5-1. Cross-section and analyzing power data for ^{28}Si(n,n$_0$) and (n,n$_1$) at 17 MeV. The curves are coupled-channels calculations.

6. Scattering of Polarized Neutrons from Heavy Nuclei (P. P. Guss, C. E. Floyd, R. L. Walter, J. P. Delaroche)

Data for ^{116}Sn and ^{120}Sn were obtained at 8-17 MeV for $\sigma(\theta)$ and at 10 and 14 MeV for $A_y(\theta)$, as previously reported. The data have been analyzed in a vibrational model with deformed central and spin-orbit terms. Furthermore, this CC model was used as a basis for a spherical model. Consistency of the models with (p,p) data for $\sigma(\theta)$ and $A_y(\theta)$ was also checked. The results of the experiment and the analyses comprise a portion of the Ph.D. thesis of P. Guss; a paper on this work will be drafted soon. Measurements of $A_y(\theta)$ at 17 MeV are underway. These new data will permit a measure of the accuracy of the energy dependence of the models of Guss et al.

Spherical optical model analyses have been proceeding for ^{208}Pb(n,n). In Sec. All we note the findings from analyses of the 10-MeV data. Before proceeding onto the global model for ^{208}Pb, we were required to make additional modifications to the code GENOA originally obtained from F. Perey of ORNL. The revised code, which also had been modified earlier to include the Mott-Schwinger interaction, now permits us to include an imaginary spin-orbit interaction W_{so} with a geometry separate from the real spin-orbit interaction V_{so}. This was necessary in order to efficiently determine if the data prefer $r_{W_{so}} > r_{V_{so}}$ at energies other than 10 MeV, as re report in our manuscript to Physical Review. The global analysis for ^{208}Pb should be restarted within two months.

7. Small Angle Scattering of Polarized Neutrons

As neither the CC nor the spherical optical model (SOM) calculations that we made last year could explain our $A_y(\theta)$ data for ^{208}Pb and ^{54}Fe at forward angles, it became necessary to test the accuracy of the approximation method in which the Mott-Schwinger interaction was inserted into the SOM code GENOA. (This test became very important when we were able to ascribe most of the forward angle discrepancy to the apparent need for an imaginary spin-orbit term.) A new optical model code was written which permitted "exact" solution of the scattering problem out to radii equal to 1000 fm. The code was run for ^{208}Pb and ^{54}Fe. The differences between our approximate method and the "exact" method were found to be small (<0.02 in $A_y(\theta)$) and not responsible for the discrepancy. A paper describing the test calculation and the results of our approximation method has been drafted.

The Mott-Schwinger effect is most noticeable for angles less than 1°, but its influence is felt out to 15°-20°. No measurements of this (classical) effect have been made above a few MeV. With our 4-m and 6-m detectors we cannot measure at equal scattering angles (on opposite sides of the beam axis) below $\theta = 18^\circ$. Therefore, we tested the small-angle-scattering detection system (obtained a few years ago from Edgewood Arsenal) for its compatibility to obtain $A_y(\theta)$ data down to 1.5°. Our initial tests look promising. This measurement will be pursued further, since the small-angle-scattering of neutrons should be compared to calculations for energies where the nuclear reaction mechanism is dominated by direct processes and where the nuclear model parameters should be better understood.

8. Effects of Coupling to Giant Resonances

Extended coupled channels calculations have been performed for neutron elastic and inelastic cross sections and analyzing powers for vibrational nuclei with $40 < A < 208$ to determine the sensitivity of these observables to the coupling to isoscalar giant resonances. The calculations concentrated on the neutron energy region between 10 and 17 MeV, and the 10 MeV results for $^{116,120}Sn$ and ^{208}Pb and 12 MeV results for ^{40}Ca have been published in Physical Review 27 (1983) 2385.

9. Studies of (p,n) Reaction on Light Nuclei (R. C. Byrd, K. Murphy, R. L. Walter)

Four separate projects are being developed as part of the thesis work of K. Murphy. First, the preliminary $^{11}B(p,n)^{11}C$ and $^{13}C(p,n)^{13}N$ analyzing powers shown at the Santa Fe polarization conference have been reanalyzed and are being combined with cross section and polarization measurements taken from the literature. The results will be used as discussed in Secs. B-11 and B-12 to study isospin symmetry breaking and spin flip asymmetries in these reactions.

The $^{13}C(p,n)^{13}N$ and $^{15}N(p,n)^{15}O$ cross sections and analyzing powers measured in the energy range from 15 to 17 MeV are being prepared to extend the Lane model coupled-channels analyses of ref. 1 to higher energies.

The $^{15}N(\vec{p},\vec{n})^{15}O$ $K_y^{y'}(0^\circ)$ data reported by Walter *et al.*[2] have been corrected for backgrounds and are being combined with measurements of the 0° cross section. These results will be combined with the measurements of Chew et al.[3] to provide a more complete $\sigma(\theta)$ data set.

Measurements of the $^{11}B(p,n)^{11}C$ cross section and analyzing power have been made at energies up to 17 MeV. These results will be combined with the $(\vec{n},n)$ analyzing powers of section B4 in a simultaneous Lane model analysis of the ^{10}B and ^{11}B + nucleon systems.

REFERENCES (Section B9)

1. R. C. Byrd et al., Nucl. Phys. A351 (1981) 189
2. R. L. Walter et al., in Polarization Phenomena, p. 1326
3. S. H. Chew et al., Nucl. Phys. A298 (1978) 19

10. Cross Section Measurement and Lane Model Analysis for the $^9Be(p,n_0)^9B$ Reaction

This work has been published in Nuclear Physics A399 (1983) 94. As discussed in Sec. B3, an extension of this analysis is being prepared which will attempt to extrapolate the results into the 15-30 MeV energy range and include new TUNL analyzing powers for $(\vec{n},n)$ scattering.

11. Comparisons of Polarization $P(\theta)$ and Analyzing Power $A(\theta)$ for the $^9Be(p,n_0)^9B$ Reaction (R. C. Byrd, P. W. Lisowski, W. Tornow, R. L. Walter)

This work has been published in Nuclear Physics A404 (1983). The abstract follows:

> "A recent Lane model of the ^9Be+nucleon system raised the question of differences between the polarization $P(\theta)$ and the analyzing power $A(\theta)$ in (p,n) reactions between mirror nuclei. Since these two observables are identical under exact charge symmetry, observation of a difference would indicate the breaking of this symmetry, probably by the Coulomb interaction. This paper describes the techniques for measurements of $P(\theta)$ and $A(\theta)$ in (p,n) reactions, with an emphasis on the elimination of systematic errors and the determination of background contributions. Measurements of both observables were made for the $^9Be(p,n_0)^9B$ reaction at several angles for

> energies from 3 to 10 MeV. The results are combined with previous measurements to develop data sets for a comprehensive comparison of P(θ) and A(θ). Previous A(θ) values agree well with the present measurements, while most of the earlier P(θ) data are shown to be in error. Our data show that there do exist sizeable differences between P(θ) and A(θ) at energies from E_p = 5-7 MeV. The existence of such differences in light nuclear systems is consistent with recent shell-model calculations for the $^{11}B(p,n_0)^{11}C$ reaction."

This paper presents the results of the first measurements of (p,n) polarizations and analyzing powers to be carried out at the same laboratory. As shown in Fig. B11-1, clear differences exist between these two observables in the energy range from 5-8 MeV. This result is consistent with the results of discussions of charge symmetry breaking,[1] spin-flip probabilities,[2] and shell-model calculations.[3]

REFERENCES (Section B11)

1. D. H. Wilkinson, Phil. Mag. 1 (1956) 379
2. P. W. Lisowski et al., Nucl. Phys. A264 (1976) 188
3. R. J. Philpott and D. Halderson, Nucl. Phys. A345 (1980) 141

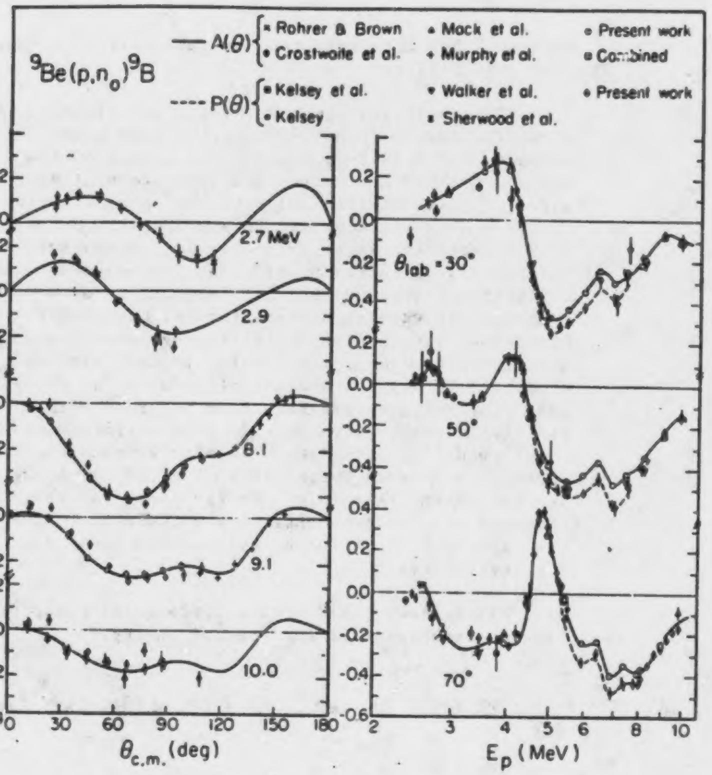

Fig. B11-1. Comparison of polarization P and analyzing power A for the ^{9}Be(p,n)^{9}B reaction. The data sets are described in detail in the publication referred to in Sec. B11. Note the difference between P and A in the 5-7 MeV energy range.

Neutron Polarization Studies

12. Comparison of $P(\theta)$ and $A(\theta)$ for the $^{15}N(p,n)^{15}O$ Reaction (R. C. Byrd, C. E. Floyd, P. P. Guss, K. Murphy, R. L. Walter)

This work has been accepted for publication in Nucl. Phys. A . The abstract follows:

> "The analyzing power $A_y(\theta)$ and polarization $P^y(\theta)$ for the $^{15}N(p,n_0)^{15}O$ reaction have been measured for E_p=4.5-11.3 MeV. The values of the two observables are nearly the same above 11 MeV, where a "quasi-elastic" view of the (p,n) reaction to the analog state should be applicable. Below 10 MeV, however, large spin-flip amplitudes and isospin-mixing ratios provide the two major conditions needed to obtain $P^y(\theta) \neq A_y(\theta)$, and dramatic differences between the two observables are seen. The size of the differences and their dependence on energy are similar to the results predicted by shell-model calculations. The $P^y(\theta)$ and $A_y(\theta)$ measurements have been combined with existing cross-section data to provide information about spin-flip processes. We also comment on the connection between comparisons of $P^y(\theta)$ and $A_y(\theta)$ in charge-symmetric (p,n) reactions and the recent controversial measurements of a difference between the values of $P^y(\theta)$ for a reaction and $A_y(\theta)$ for the inverse reaction."

Fig. B12-1 shows the dramatic differences observed between these two observables as a function of energy.

13. The Analyzing Power for the $^2H(\vec{d},n)^3He_{g.s.}$ Reaction from 5.5 to 11.5 MeV

A paper of the above title has been published in Nuclear Physics A395 (1983) 1.

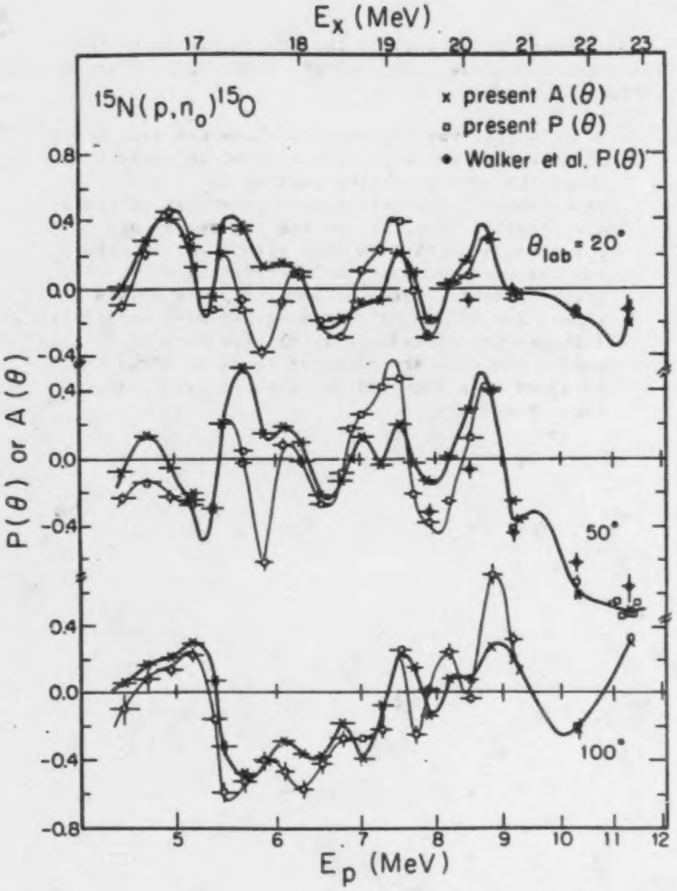

Fig. B12-1. Comparison of P(θ) and A(θ) for the $^{15}N(p,n)^{15}O$ reaction. Note the large differences between P and A in the lower-energy region. The data are described in detail in the publication referred to in Sec. B12.

Neutron Polarization Studies

14. Simultaneous Measurements of Analyzing Powers and Differential Cross Sections for $n + {}^{28}Si$

A paper of the above title was published in IEEE Transactions on Nucl. Sci. NS-30 (1983) 1132. The abstract follows:

"Scattering experiments conducted with beams of polarized neutrons give special information about the spin-sensitive part of the neutron-nucleus interaction. Carefully controlled measurements of $A_y(\theta)$ for the scattering of polarized neutrons can also give accurate values for the more conventional observable, $\sigma(\theta)$. The present paper focuses on an attempt to obtain $\sigma(\theta)$ values for ${}^{28}Si(n,n)$ from an experiment originally intended to determine only the function $A_y(\theta)$. As a test the data are compared to cross sections measured in a conventional neutron scattering experiment."

C. HIGH RESOLUTION STUDIES

1. High Resolution Measurement of the (p,p),(p,p') and (p,α) Reactions

(E. G. Bilpuch, G. E. Mitchell, G. Adams, W. Brooks, R. O. Nelson, J. F. Shriner, Jr.,* J. Vanhoy, B. Warthen, C. R. Westerfeldt)

a. Introduction

For many years our high resolution studies were restricted to targets with zero spin. Recently we have begun a series of measurements on non-zero spin targets. Odd-mass targets in the 2s-1d shell are best suited for our purposes — relatively high (p,n) threshold, relatively well separated low-lying states, and some previous capture studies. There is essentially no detailed resonance analysis of elastic scattering for odd-mass targets. For targets with spin the range of combinations of angular momenta is much greater than for zero-spin targets. This additional complexity makes the analysis much harder, but also makes the results more interesting. In addition to the interest in the detailed nuclear spectroscopy, this spectroscopic information is crucial to fundamental symmetry tests utilizing resonances. For example, violations of detailed balance in the (p,α) and (α,p) reactions though an isolated resonance, are not observable unless there is ℓ mixing [Driller *et al.*, Nucl. Phys. A317 (1979) 300]. With sufficient spectroscopic information, one can select resonances which enhance the effect of interest.

Our first experiment of this type was on ^{29}Si. After the successful analysis of these data, ^{27}Al and ^{25}Mg were studied. The ^{29}Si results have been published, while extensive analysis on ^{27}Al and ^{25}Mg is nearing completion. Further measurements on odd-mass 2s-1d shell nuclei are planned. In an extension of these measurements, we removed the sign ambiguity for entrance-channel amplitudes (for an isolated resonance) with a polarized-beam experiment. As we discuss in section e, both ℓ-mixing and a polarized beam are necessary to determine the relative sign.

b. ^{29}Si

The nucleus ^{29}Si was chosen for our first study of non-zero-spin targets. Spin J=1/2 targets lead to some simplification in the analysis. The allowed entrance channel spins are s = 0 and 1. For a $J\pi = 1/2^+$ target, natural parity resonances allow only channel-spin mixing, while unnatural parity resonances allow only ℓ mixing.

The overall results were encouraging: ℓ values were determined for essentially every resonance, J values for most resonances, and channel spin mixing ratios for resonances which were not too small. The ℓ-mixing effects were normally small -- at these energies the $(\ell+2)^{th}$ penetrability is much smaller than the ℓ^{th} penetrability. Therefore only an upper limit for ℓ-mixing was obtained for most resonances. Coherent level-level interference was also observed — since this requires that at least two channels contribute to both resonances, this effect is not observed in scattering from zero-spin targets.

More important than the specific spectroscopic results was the demonstration that analysis of scattering from targets with spin was quite feasible.

A paper has been published on this work -- R. O. Nelson, E. G. Bilpuch, C. R. Westerfeldt, and G. E. Mitchell, Phys. Rev. C27 (1983) 930. The following is the abstract of that paper:

> "The ^{29}Si (p,p) and (p,p') differential cross sections were measured in the range E_p=1.29-3.31 MeV with an overall resolution of 350-400 eV, full width at half maximum. Resonance parameters were extracted for 66 resonances with a multilevel, multichannel R-matrix analysis code; these parameters include resonance energy, total angular momentum, partial elastic and inelastic widths, and channel spin and orbital angular momentum mixing ratios. Analog states were identified, and Coulomb displacement energies and spectroscopic factors are given for seven of these analog states."

c. ^{27}Al

An extensive study was performed for proton-induced reactions on ^{27}Al. In practice the elastic and α_0 channels were important below E_p = 1.7 MeV, while between 1.7 and 2.7

MeV inelastic decay to the first two excited states of ^{27}Al was also important. Above 2.7 MeV a fifth channel, α_1 decay, was also important. The analysis of these data was much more difficult than that of ^{29}Si. There were 2, 4, or 5 channels in the R-matrix analysis, and the large entrance channel spins (2 and 3) lead to a variety of possible J values. For ℓ=3, the possible J values range from 0 to 6.

Much attention was paid to the determination of channel-spin mixing and of ℓ mixing. An extensive set of catalogs of resonance shapes for various mixtures was created to aid in the extraction of these parameters. The analysis of these data has just been completed — several papers will be prepared in the near future.

These ^{27}Al results (together with the ^{29}Si data) served as the basis for the Ph.D. dissertation of R. O. Nelson. The following is the abstract of his dissertation:

> "Excitation functions for proton elastic scattering and for proton induced reactions were measured with the EN Van de Graaff and associated high resolution system at TUNL for two odd-mass targets. Excitation functions for ^{29}Si(p,p), (p,p_1), and (p,p_2) were obtained in the range E_p = 1.29 to 3.30 MeV, and the ^{27}Al(p,p), (p,p_1), (p,p_2), (p,α_0), and (p,α_1) differential cross sections were measured in the range E_p = 0.92 to 3.05 MeV. The data were measured at four angles with an overall resolution that varied between 350 - 450 eV, full width at half maximum.
>
> The measured excitation functions were analyzed with a multi-level, multi-channel R-matrix formalism. The parameters extracted from the data include the resonance energy, total angular momentum, partial elastic and reaction widths, and channel spin and orbital angular momentum mixing ratios. Resonance parameters were determined for 66 resonances in ^{30}P in the range E_x = 6.85 to 8.79 MeV, and for 104 resonances in ^{28}Si in the range E_x = 12.47 to 14.53 MeV. The dependence of the resonance shapes on the channel spin mixing ratio and on the ℓ-mixing ratio was investigated for proton scattering on target nuclei with $J^\pi = \frac{1}{2}^+$ and $\frac{5}{2}^+$.
>
> Seven isobaric analog states were

identified in ^{30}P and eighteen analog states were identified in ^{28}Si. Coulomb energies and proton spectroscopic factors were determined and the analog strengths compared with the parent state (d,p) spectroscopic factors.

The proton elastic scattering width of the 6^-, $T = 1$, stretched state at $E_x = 14.36$ MeV in ^{28}Si was measured. Results of calculations relating the measured width to the strength of this state in intermediate energy inelastic scattering are presented.

A precise value of the ℓ-mixing ratio was determined for the 2^+ resonance at $E_p = 1.365$ MeV from a measurement of the $^{27}Al(p,\alpha_0)$ reaction. This measurement is relevant to a previous test of time reversal invariance."

d. ^{25}Mg

The ^{25}Mg (p,p) reaction has been studied in the energy region E_p=0.800 to 2.190 MeV. Inelastic scattering was observed to the first and second excited states of ^{25}Mg for a few resonances. Targets of enriched Mg (99.7% ^{25}Mg) were prepared by evaporation of MgO. Most of the targets used ranged in thickness from 0.5 to 1.0 $\mu g/cm^2$; the backings were 5 $\mu g/cm^2$ C foils. Excitation curves were measured at four angles with an overall resolution of 400 eV.

Forty-six resonances were observed and a preliminary analysis has been performed on these resonances. Most of the resonances are s- or p-wave resonances (10 ℓ=2, 2 ℓ=3), with significant channel spin mixing and minimal ℓ-mixing. Since the spin and parity of ^{25}Mg are $5/2^+$, the entrance channel spin combinations are the same as for ^{27}Al. However, for these data elastic scattering is essentially the only process.

Results of previous measurements and of recent (coordinated) work by P. M. Endt are combined with our results to minimize J value ambiguities. The analysis of these data will be completed in the near future.

e. Measurement of Relative Signs of Entrance Channel Amplitudes

Since channel spins add incoherently, the relative signs of channel spin amplitudes cannot be determined in conventional experiments. In the method we used, a polarized beam is necessary, but not sufficient — appreciable ℓ-mixing is also required in order to determine the relative signs of channel spin amplitudes. In the only previous comparable experiment, Snover et al. (Phys. Rev. Letters 44, (1980) 927) used interference between E1 capture and a resonance to determine the sign between the s and d components of the capture.

To achieve a single exit channel and thus simplify the analysis, we utilized the $(\vec{p},\alpha_0)$ reaction with the α_0 decay to a 0^+ state. Previous work by de Meijer et al. [Nucl. Phys. A155, (1970) 109] had identified many resonances in the reaction $^{39}K(p,\alpha_0)^{36}Ar$; a 2^+ resonance at $E_p = 3.214$ MeV was chosen for study. (Our value for the resonance energy is $E_p = 3.212 \pm 0.002$ MeV.) Since the ground state of ^{39}K has $J^\pi = 3/2^+$, a 2^+ resonance can be formed with orbital angular momenta $\ell=0$, 2, and 4, and allowed channel spins are s=1 and s=2. The $\ell=4$ channel is neglected due to its extremely low penetrability. A single-level approximation is used for the elements of the scattering matrix S. The angular distribution for an isolated 2^+ resonance in the $^{39}K(\vec{p},\alpha_0)$ reaction can then be written

$$W_\alpha(\theta\phi) = a_0[1 + a_2P_2(\theta) + a_4P_4(\theta) + a_{21}P_y\cos\phi\, P_2^1(\theta)],$$

where P_2^1 is an associated Legendre function, P_2 and P_4 are Legendre polynomials, P_y is the component of the beam polarization vector normal to the reaction plane, and θ and ϕ are the polar and azimuthal detection angles.

We use three subscripts for the reduced width amplitudes: the first denotes the representation, the second the value of the orbital angular momentum ℓ, and the third s. The three entrance channel amplitudes are γ_{s02}, γ_{s21}, and γ_{s22}.

If only one ℓ value contributes, then $a_{21}=0$, and the measurement with a polarized beam provides no new information. This is because the single-level approximation we have employed includes only Coulomb and hard sphere phase shifts which are dependent only on ℓ for the non-resonant phase shift ξ_ℓ. Since the polarization-dependent part of the cross section depends only on the imaginary part of SS*, the quantity $\xi_{\ell_1} - \xi_{\ell_2} + \xi_{\ell_1'} - \xi_{\ell_2'}$ must be non-zero or a_{21} will vanish. (Unprimed terms refer to entrance channel, primed to exit channel.) Because there is only one possible decay amplitude for this reaction, $\ell_1' = \ell_2'$ and we must have $\ell_1 \neq \ell_2$ for this phase to be nonzero. Therefore ℓ-mixing must be present for the polarization-dependent term to contribute to the angular distribution.

The resonance was first studied with unpolarized beam to verify the previous measurement and to confirm that ℓ-mixing was present. Targets consisted of natural KI (93.26% ^{39}K) evaporated to thicknesses of 2-3 μg/cm^2 K onto 5 μg/cm^2 carbon foils. Five surface barrier detectors were used to observe both elastically scattered protons and α particles. The overall resolution was 400 eV. The angular distribution measurement determined the coefficients a_2 and a_4. These results allow four possible solutions for the mixing parameters $\delta_1 = \gamma_{21}/\gamma_{02}$ and $\delta_2 = \gamma_{22}/\gamma_{02}$ which are listed in Table C1-1. Two of the four solutions can be eliminated by comparison with the elastic scattering data. R-matrix fits were generated for seven resonances near 3.2 MeV. The parameters of the other six resonances were fixed, and fits for the 3.212 MeV resonance were determined for each pair of solutions. Because reactions with unpolarized beams are incoherent in channel spin, the sign of γ_{22}/γ_{21} does not affect the fits. Fits for the two solutions are shown in Fig. C1-1 for both the (p,p) and (p,α) reactions at $\Theta_{lab} = 160^\circ$. The fit for the two solutions with $\delta_2^0 = 3.32$ is shown in the lower half of Fig. C1-1, and the fit for the solutions with $\delta_2^2 = 1.44$ shown in

Table C1-1

Entrance Channel Mixing Ratios
for a 2^+ Resonance in ^{40}Ca

δ_1	δ_2	Consistent with (p,α)	 (p,p)	 $(\vec{p},\alpha_0)$
-1.00	+1.44	yes	yes	yes
+1.00	+1.44	yes	yes	no
-2.23	+3.32	yes	no	---
+2.23	+3.32	yes	no	---

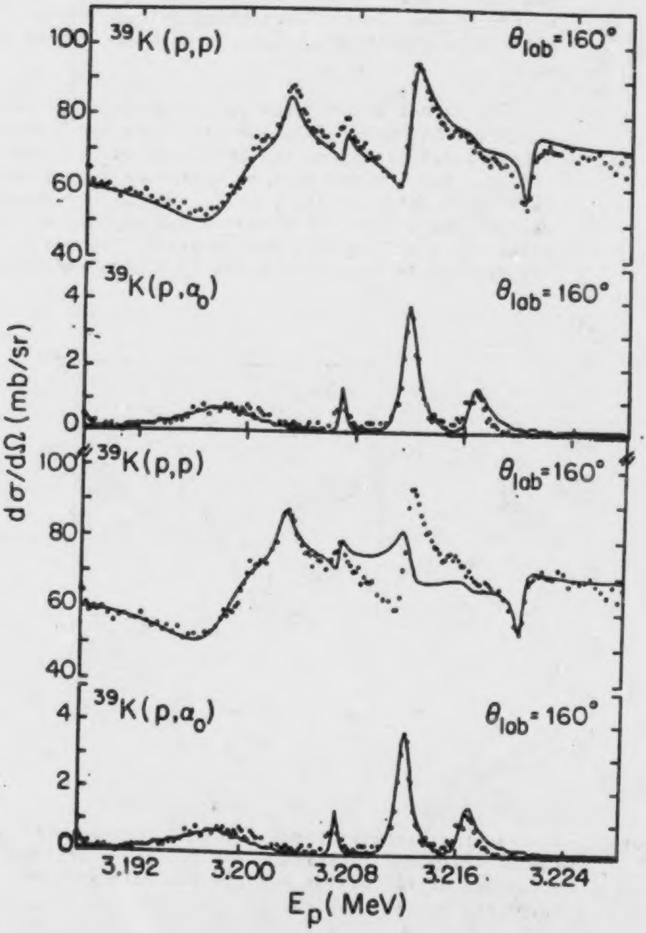

Fig. C1-1. Data and approximate R-matrix fits for ^{39}K(p,p) and ^{39}K(p,α_0) in the region of the 2^+ resonance at E_p= 3.212 MeV. The upper half of the figure shows fits for the solutions with δ_2 = 1.44, while the lower half shows fits for the solutions with δ_2 = 3.32.

the upper half. Solutions with the smaller value of δ_2 reproduce the elastic scattering data for this resonance quite well, while the solutions with the larger value of δ_2 do not.

To choose between the two remaining solutions, we utilized the high resolution system on the TUNL FN Van de Graaff accelerator and the TUNL Lamb shift polarized ion source. Six surface barrier detectors were located in left-right pairs at 115°, 135°, and 155° to detect the charged particles. From the $(\vec{p},\alpha_0)$ angular distribution a value $a_{21} = 0.32 \pm 0.02$ was obtained. The six data points are plotted in Fig. C1-2 along with the predicted

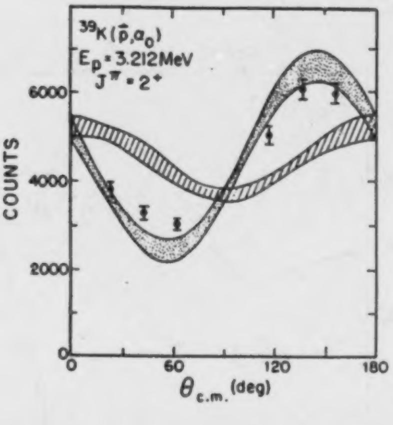

Fig. C1-2. The angular distribution for the 2^+ resonance at $E_p = 3.212$ MeV in the $^{39}K(\vec{p},\alpha_0)$ reaction. The two bands represent the predicted distributions for the two solutions obtained from (p,p) and (p,α_0) studies.

distributions for the two possible solutions. For each solution the uncertainties in the mixing parameters have been incorporated into the predicted distribution, which is plotted as a band. For a single level with definite parity, angles with $\theta < 90°$, $\phi = 0°$ are equivalent to angles with $\theta > 90°$, $\phi = 180°$; thus for compactness the three data points with $\phi = 180°$ are plotted at $180°-\theta$. The polarized beam data clearly agree better with one prediction than the other: the preferred solution corresponds to $\gamma_{s21}/\gamma_{s02} = -1.00$, $\gamma_{s22}/\gamma_{s02} = +1.44$.

These results provide the first unique determination of the relative phases for entrance channel amplitudes in the formation of an isolated compound nuclear nuclear resonance. Since appreciable ℓ-mixing is required with this method to determine the relative phase, it appears extremely difficult to obtain such information for a large set of resonances. A paper on this work is in preparation.

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2. Amplitude Correlations (G. E. Mitchell, E. G. Bilpuch, P. Ramakrishnan, J. F. Shriner, Jr.,* C. R. Westerfeldt)

a. General

The study of amplitude correlations has continued to be emphasized during the past year. In these measurements magnitudes and relative signs are determined for decay amplitudes from isolated compound nuclear resonances. The (p,p') reaction is employed on zero-spin targets. The inelastic decay from the compound state (J^π) to the excited state (2^+) proceeds in general via several channels -- it is the relative signs of these amplitudes which are determined. The bulk of the data are for $3/2^+$, $3/2^-$, and $5/2^+$ resonances. For $3/2^-$ and $5/2^+$ resonances singles measurements of the p' and γ-ray angular distributions are sufficient to determine uniquely the mixing parameters, while for $3/2^+$ resonances an additional experiment is required (see section e below).

These data provide the only set of amplitude correlations for nuclear physics, and thus permit the most sensitive tests of doorway state and statistical theory. Some of our first results verified the key phase relation for doorway states [A. M. Lane, T. R. Dittrich, G. E. Mitchell, and E. G. Bilpuch, Phys. Rev. Letters 41 (1978) 454]. We also provided the first explicit proof of the Krieger-Porter reduced width amplitude distributions [B. H. Chou, G. E. Mitchell, E. G. Bilpuch, and C. R. Westerfeldt, Phys. Rev. Letters 45 (1980) 1253]. The general result is that amplitude correlations are surprisingly large and common. Possible origins of these correlations are discussed in section b, while results for specific nuclei are presented in the other sections.

An overview of these results was presented in invited talks at the Southeastern Section of the American Physical Society in Lexington, Kentucky -- [G. E. Mitchell, Bull. Am. Phys. Soc. 27 (1982) 742] — and at the conference on the Application of Accelerators at Denton, Texas -- [G. E. Mitchell, Bull. Am. Phys. Soc. 27 (1982) 761]. An extended version of the latter talk was published in the conference proceedings — [G. E. Mitchell, IEEE Transactions on Nuclear Science, Vol. NS-30 (1983) 1115].

b. Direct Reactions

The Bohr compound-nucleus picture of reactions predicts that there should be no correlation between resonance amplitudes of pairs of channels. In contrast, direct reaction theory predicts that such correlations must occur [C. Bloch, Nucl. Phys. 4 (1957) 503; J. Hüffner, C. Mahaux, and H. A. Weidenmüller, Nucl. Phys. A105 (1967) 489]. Unlike the many other predictions of direct reaction theory, this had never been tested experimentally. We interpret the large amplitude correlations as reflecting direct reactions between the inelastic channels. A paper has been published on this result [A. M. Lane, G. E. Mitchell, E. G. Bilpuch, and J. F. Shriner, Jr., Phys. Rev. Letters 50 (1983) 321]. The following is the abstract of that letter:

> "It is shown that the new proton resonance data on targets A~48 provide a crucial check on the validity of direct reaction theory, viz. the existence of amplitude correlations between channels. These are often large ($|\rho| \geq 0.5$) and are not simply related to width correlations. Analysis with a simple reaction model shows that the large correlations must imply some failure of the distorted-wave Born-approximation theory of direct reactions."

The generality of these results is unknown. Data for other regions of the nuclear periodic table are badly needed to test the validity of the random phase approximation.

c. ^{44}Ca

An extensive study of $\ell=1$ and $\ell=2$ resonances has been performed for the ^{44}Ca(p,p'γ) reaction. This work formed the basis for the Ph.D. dissertation of J. F. Shriner, Jr. The following is the abstract of his dissertation:

> "Magnitudes and relative signs of inelastic proton decay amplitudes have been determined for 23 $3/2^-$ resonances and 53 $5/2^+$ resonances in ^{45}Sc by measuring angular distributions of inelastically scattered protons and of deexcitation gamma-rays in the ^{44}Ca (p,p'γ) reaction. The experiment was performed with an overall energy resolution of 350-400 eV at the KN Van de Graaff accelerator and high resolution system of the Triangle Universities Nuclear Laboratory.
>
> Statistical analyses were performed on reduced widths and reduced width amplitudes for $3/2^-$ and $5/2^+$ resonances. Strong channel-channel correlations were observed for amplitudes, including the first case for $\ell=1$ resonances of a large amplitude correlation over a broad energy range. These correlations are interpreted as evidence for a direct reaction component in the scattering matrix.
>
> It is shown that under suitable conditions, the ($\vec{p}$,α_0) reaction can be employed to determine both magnitudes and relative signs of entrance channel amplitudes. A single resonance in ^{40}Ca was studied with the TUNL FN tandem Van de Graaff accelerator, and the mixing parameters for the entrance channel were extracted."

Very strong ampltude correlations were observed for both the $5/2^+$ and $3/2^-$ resonances [J. F. Shriner, Jr., E. G. Bilpuch, C. R. Westerfeldt, and G. E. Mitchell, Z. Phys. A305 (1982) 307]. The present $3/2^-$ data have been combined with the earlier data of Dittrich *et al*. to produce a reasonable sample size. For ease of presentation these $3/2^-$ data have been combined with similar data in ^{51}Mn -- the abstract of this paper is given in section d.

d. ^{50}Cr

An extensive study of ℓ=1, 2, and 3 resonances was performed with the ^{50}Cr(p,p'γ) reaction. This work formed the basis for the Ph.D. dissertation of K. M. Whatley. The following is the abstract of her dissertation:

> "Detailed angular distribution measurements on elastically scattered protons and de-excitation γ-rays in the ^{50}Cr(p,p') and ^{50}Cr(p,p'γ) reactions were performed for 107 resonances in ^{51}Mn in the proton energy range 3.0-4.4 MeV. An overall resolution of 425 eV was obtained with the tandem Van de Graaff accelerator and the high resolution system at the Triangle Universities Nuclear Laboratory.
>
> Spin and parity assignments for the 107 resonances studied were as follows: $1/2^+$ (4); $1/2^-$ (6); $3/2^-$ (30); $3/2^+$ (20); $5/2^+$ (38); $5/2^-$ (7); $7/2^+$ (1); and $9/2^+$ (1). Mixing ratios for the inelastic decay amplitudes were uniquely determined for all resonances except those assigned $J^\pi = 1/2^+, 1/2^-$, or $3/2^+$. The J = 1/2 resonances provide no relevant information. For $3/2^+$ resonances, insufficient information is obtained from this experiment to determine a unique solution for the mixing ratios.
>
> Statistical studies were performed on the set of $3/2^-$ resonances and on the set of $5/2^+$ resonances. Strong channel-channel correlations were observed in the distributions of the reduced widths and the reduced width amplitudes for $5/2^+$ resonances. The existence of such correlations is a violation of the extreme statistical model. The present results agree with the reduced width amplitude distribution of Krieger and Porter which includes channel-channel correlations."

The $3/2^-$ data were combined with similar data from ^{45}Sc. A paper has been accepted for publication in the Zeitschrift für Physik (J. F. Shriner, Jr., K. M. Whatley, E. G. Bilpuch, C. R. Westerfeldt, and G. E. Mitchell). The following is the abstract of that paper:

> "Magnitudes and relative signs of reduced width amplitudes for two inelastic decay channels were obtained for $3/2^-$ resonances in ^{45}Sc and ^{51}Mn. Width and amplitude correlations were determined, and the first large amplitude correlation has been observed for $\ell=1$ resonances over a broad energy range. These results are consistent with the large amplitude correlations previously observed for $3/2^+$ and $5/2^+$ resonances."

A paper on the $5/2^+$ resonances in ^{51}Mn has been accepted for publication in Journal of Physics G [K. M. Whatley, E. G. Bilpuch, G. E. Mitchell, J. F. Shriner, Jr. and C. R. Westerfeldt]. The following is the abstract of that paper:

> "A high resolution study of proton inelastic decay from $5/2^+$ resonances in ^{51}Mn has been performed in the energy range E_p = 3.26 to 4.28 MeV. Magnitudes and relative signs were determined for three decay channels for 38 $5/2^+$ resonances in ^{51}Mn. Very large amplitude and width correlations were observed."

The ^{51}Mn data provide good examples of these amplitude correlation results. Fig. C2-1 shows typical angular

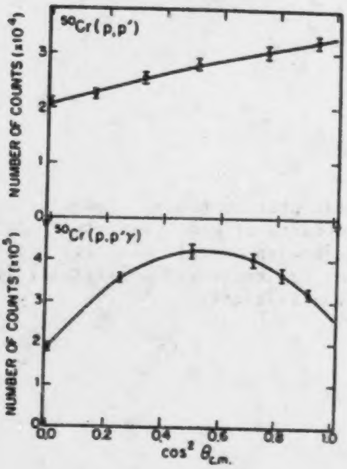

Fig. C2-1. Angular distributions for the $5/2^+$ resonance at E_p=3.2867 MeV. The solid lines are fits to the data. The departure from linearity in the γ-ray angular distribution indicates a large a_4 coefficient.

distributions. Plotted in this manner (versus $\cos^2\theta$), it is clear that both P_2 terms are positive, and that for the protons the P_4 term is close to zero, and for the γ-rays the P_4 term is large and negative. The reduced width distributions in Fig. C2-2 are in excellent agreement with

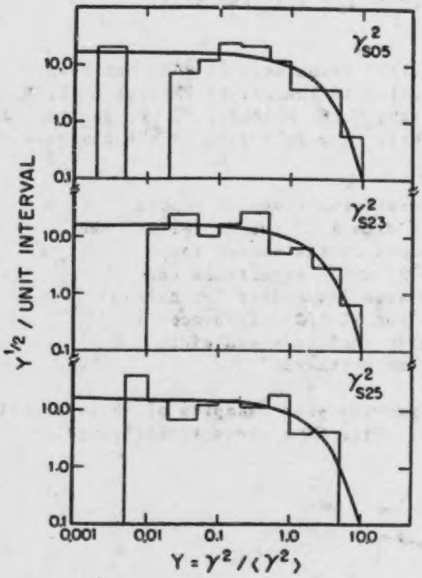

Fig. C2-2. Distributions of reduced widths for the three inelastic channels of $5/2^+$ resonances in ^{51}Mn. The smooth curves are normalized Porter-Thomas distributions. The data are in the channel spin representation.

the normalized Porter-Thomas distributions. However, as shown in Fig. C2-3, the products of width amplitudes do not oscillate about zero, but show an overall positive trend. These large positive slopes are reflected quantitatively as large linear correlation coefficients.

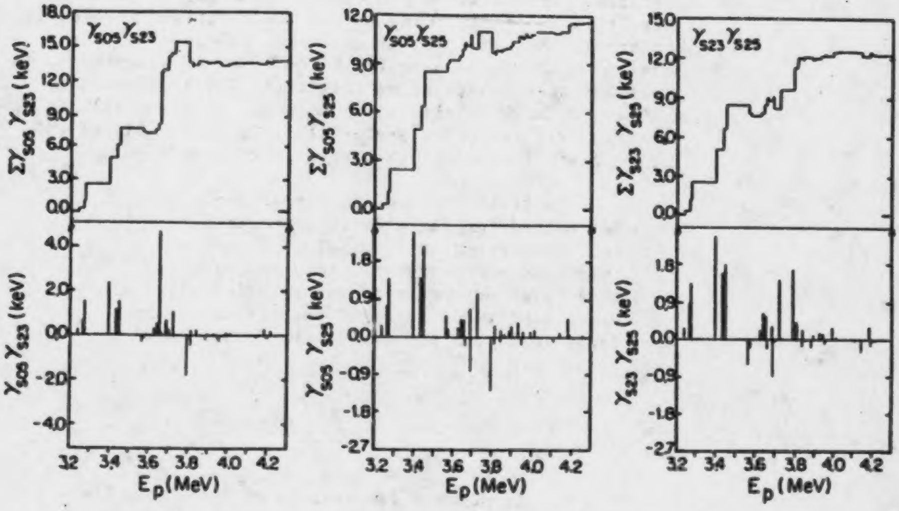

Fig. C2-3. Products of inelastic reduced width amplitudes and cumulative sums of products of reduced width amplitudes for $5/2^+$ resonances in ^{51}Mn.

e. Angular Correlation for $3/2^+$ Resonances in ^{49}V

For $3/2^+$ resonances the angular distributions are limited to P_2 terms, and the two singles measurements provide two quadratic equations in two unknowns. The result is two acceptable pairs of solutions. We removed this ambiguity by measurement of γ-rays in coincidence with inelastically scattered protons at $\theta_{p'} = 135^\circ$. The correlations corresponding to the two solutions were quite different. For one pair of channels, the relative sign between amplitudes was positive for 29 of 30 resonances. A paper has been published on this topic [P. Ramakrishnan, B. H. Chou, G. E. Mitchell, E. G. Bilpuch, R. O. Nelson, J. F. Shriner, Jr., and C. R. Westerfeldt, Z. Phys. A311 (1983) 157]. The following is the abstract of that paper:

> "Amplitude and width correlations were determined for three decay channels for 30 $3/2^+$ resonances in ^{49}V. Singles and coincidence measurements were employed in this first determination of relative signs of decay amplitudes for $3/2^+$ resonances. Very large amplitude and width correlations are observed."

f. ^{56}Fe

One of the primary limitations of these amplitude correlation studies is the limited sample size. Our extensive work on ^{56}Fe [W. A. Watson, E. G. Bilpuch, and G. E. Mitchell, Z. Phys. A300 (1981) 89; Phys. Rev. C24 (1981) 1997] provides a large number of resonances suitable for study. Since the $\ell=2$ resonances were more numerous and had larger inelastic yields than the $\ell=1$ resonances, we decided to perform a study for $\ell=2$ resonances in ^{57}Co.

Highly enriched targets (99.93% ^{56}Fe) in the form Fe_2O_3 were prepared with typical thickness of 2-3 $\mu g/cm^2$. The backings for the γ-ray angular distributions and for the lower energy p' angular distributions were 2-3 $\mu g/cm^2$ of carbon, while 20 $\mu g/cm^2$ Al foils were used for the higher energy p' angular distributions. Six NaI(Tl) crystals were employed for the γ-ray angular distributions and five surface barrier detectors for the p' angular distributions. The overall resolution was approximately 350-450 eV.

Preliminary results have been obtained for 160 $\ell=2$

resonances between $E_p = 3.11$ and 4.00 MeV. The γ-ray angular distributions provide a spin assignment of $J^\pi = 5/2^+$ for 108 resonances and $J^\pi = 3/2^+$ for 52 resonances. The proton angular distributions have been measured for approximately 100 resonances (up to $E_p \simeq 3.77$ MeV). The remaining data should be completed in the next few months. This set should comprise the most extensive resonances decay data for amplitude correlations.

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D. CHARGED PARTICLE EXPERIMENTS

1. Studies of Isospin Mixing Using High Resolution Beams

a. A Study of Isospin Mixing in Light Nuclei Via Elastic Proton Scattering (J. F. Wilkerson, R. E. Anderson, T. B. Clegg, E. J. Ludwig, W. J. Thompson)

A systematic study of isospin mixing in light nuclei has been performed by measuring the proton elastic-scattering reduced widths of high-lying T = 3/2 states in ^{17}F, ^{25}Al, ^{29}P, ^{33}Cl, and ^{37}K. Many of the high-lying T = 3/2 states in the A = 25, 29, 33, and 37 nuclei were identified by the isospin-allowed (p,t) and (p,^{3}He) reactions performed at Princeton at E_p = 40 MeV and at the Indiana University Cyclotron facility at E_p = 60 MeV. The proton reduced widths, which characterize the isospin mixing, were obtained by measuring elastic-proton scattering on A = 4n, T_z = 0 target nuclei and observing the isospin forbidden T = 3/2 resonances corresponding to high-lying T = 3/2 states in the A = 4n + 1, T_z = -1/2 nuclei. The (p,p) measurements were performed using the TUNL high-energy-resolution polarized proton beam. These data have now been completely analyzed and proton reduced widths obtained for eighteen T = 3/2 states in the nuclei under study.

The results show several interesting features;

1) Within a given compound system the widths do not increase with increasing excitation energy as might be expected. (Should isospin mixing be dominated by mixing of the T = 3/2 states with surrounding T = 1/2 levels, an increase in level density which occurs at increased excitation energy would produce increased mixing and result in larger reduced widths for the higher-lying T = 3/2 states). In fact, for the T = 3/2 levels in ^{29}P, the reduced widths decrease somewhat with excitation energy in the compound system as shown in Fig. D1-1.

2) There is a general increase in isospin mixing with mass number A in these light nuclei which is largely independent of nuclear structure. However, there is a surprising oscillation of period A = 8 displayed by the average proton reduced widths as shown in Fig. D1-2. The

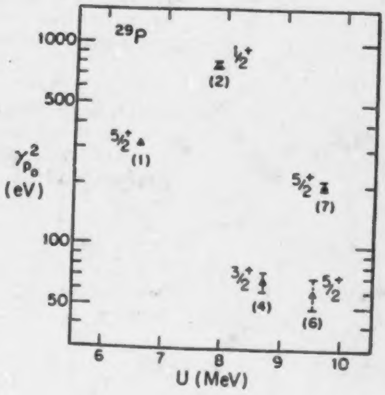

Fig. D1-1. The proton reduced widths $\gamma_p{}^2$ for the p_0 decays of the T=3/2 states in ^{29}P to the T_z=0 ^{28}Si ground state are plotted versus adjusted excitation energy U in MeV. The spins and parities are indicated. All measurements are from the current work. The dashed error bar indicates uncertainty in the extraction of the sixth T=3/2 reduced width.

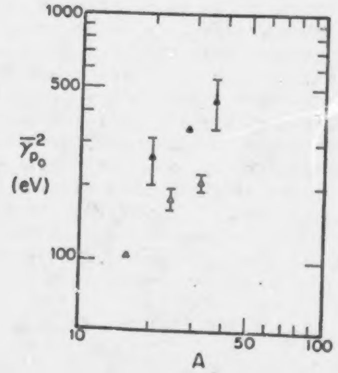

Fig. D1-2. The average proton reduced widths $\vec{\gamma}_p{}^2$ for p_0 decays of T-3/2 states in A=4n+1 T_z=-1/2 nuclei to the T_z=0 A=4n ground states are plotted versus mass number A. The oscillation of the reduced widths for A=8n (open points) and A=8n+4 (solid points) target nuclei is apparent.

average proton reduced width for a given nucleus is the average of all of the reliably measured $T = 3/2$ proton elastic-scattering reduced widths for that nucleus. This behavior has yet to be explained by any conventional isospin mixing mechanism.

An effort has begun to attempt to extract the amplitudes for Coulomb mixing in the target and compound system based on these data, the neutron reduced widths for $T = 3/2$ states in $A = 4n + 1$, $T_z = + 1/2$ nuclei, and α reduced widths for the decay of $T = 2$ states in $A = 4n$ nuclei.[1]

b. A Study of Isospin Mixing in Light Nuclei Via Elastic Alpha Scattering (R. E. Fauber, T. B. Clegg, B. C. Karp, E. J. Ludwig, W. J. Thompson)

In an effort to expand upon previous studies of isospin mixing in light nuclei, we have used elastic α scattering from ^{24}Mg targets to study the isospin forbidden formation and decay of the lowest $T = 2$ state in ^{28}Si. A similar experiment, performed by Ikossi, et al.,[2] determined the resonance width and α partial decay width using a poorer experimental resolution than intended in the present work. Using a 1.5 microgram/sq. cm. ^{24}Mg target, we produced an excitation function with energies in the range of 6.100 to 6.120 MeV in 1 keV steps. A resonance was observed with a total width of about 3 keV. This width includes the effect of beam resolution, Doppler broadening, target straggling, and resonance width. Furthermore, we were able to obtain the ^{4}He$^+$ beam resolution by a direct measurement[3] using the high resolution system at TUNL. This resolution was determined to be approximately 900 eV. (See Fig. D1-3.) In the future we hope to refine the α beam resolution measurement technique and study $T = 2$ states in other $A = 4n$ nuclei.

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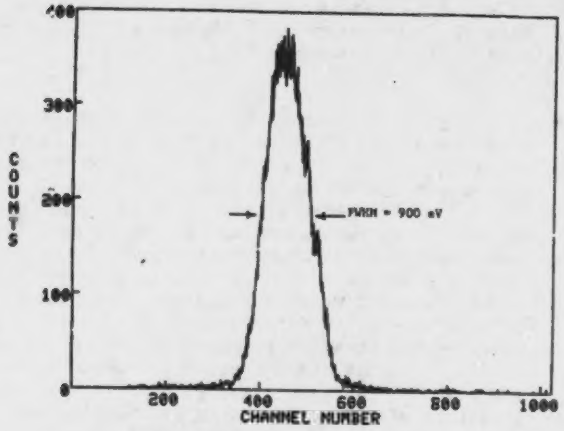

Fig. D1-3. Beam energy spread measurement of a 6.1 MeV α particle beam. This measurement technique is described in detail in ref. 2. Each channel corresponds to 8.4 eV incident energy spread.

2. Scattering Studies with Polarized Protons

a. Nucleon-Nucleus Global Optical Model Parameterization (R. L. Varner, W. J. Thompson, T. B. Clegg)

Work is in progress on the TUNL plan to measure nucleon-nucleus elastic scattering $(\vec{p},p)$ and $(\vec{n},n)$ for an optical model analysis global in energy, A, Z, and incident nucleon.[1,2] The proton elastic scattering measured at 16 MeV to date include, ^{40}Ca, $^{48,50}Ti$, $^{54,56}Fe$, $^{63,65}Cu$, $^{76,78,80,82}Se$, ^{90}Zr, $^{116,120,124}Sn$, $^{134,136,138}Ba$, ^{208}Pb, ^{209}Bi, and, ^{238}U. These data are now being reduced and analyzed in the initial steps of the global parameterization. Further $(\vec{p},p)$ data have been made available by H. Sakaguchi from Osaka (measured at 65 MeV), and by K. Yagi from Tsukuba (measured at 22 MeV). The inclusion of these data will help extend our analysis.

b. Structure of Low-Lying States of ^{76,78,80,82}Se Deduced from $(\vec{p},p')$ Scattering at 16 MeV (J. P. Delaroche,[+] R. L. Varner, T. B. Clegg, R. E. Anderson,[++] B. L. Burks, E. J. Ludwig, J. F. Wilkerson[+++])

Angular distributions of cross section and analyzing power have been obtained for elastic and inelastic scattering of 16-MeV protons leading to the first two 2^+ states and the lowest excited 0^+, 4^+ and 3^- levels of ^{76,78,80,82}Se. Results have been analyzed in the coupled channels framework assuming the Vibrational Model, the Rotation-Vibration Model, the Asymmetric Rotational Model (ARM) and its extension to beta-vibrational states. There is no one model which can describe simultaneously all the data. However, we find from our ARM-based analysis, which provides the best overall description of the even-parity states, evidence for different deformations for the first and second 2^+ states. Also we observe that the nuclear structure of ^{82}Se seems to be quite different from that of the lighter isotopes studied. We find, too, that the 3^- levels of ^{76,78,80}Se do not behave as simple vibrational octupole states. Nuclear deformations extracted from the present measurements have been compared with those from earlier (n,n') scattering and Coulomb excitation measurements. We have also examined the need for complex and/or deformed spin-orbit potentials.

A paper describing this work has been submitted for publication in "Nuclear Physics".

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c. Investigation of Nuclear Structure in The Krypton Isotopes (R. Tailor, R. L. Varner, R. E. Anderson, T. B. Clegg, B. C. Karp, E. J. Ludwig, W. J. Thompson)

With the aim of obtaining nuclear-structure information for the Krypton isotopes, cross sections and analyzing power angular distributions have been measured for ^{86}Kr$(\vec{p},p')$ at an incident energy of 16 MeV. The gas was enriched to 99.8% in ^{86}Kr and confined in a gas cell at about 1/3 atmosphere pressure.

The elastic and inelastic scattering measurements for 0_1^+, 2_1^+, 0_2^+, 2_2^+, 4_1^+, and, 3^- were made from 30° to 155° in 5° steps. The elastic-scattering measurements only were extended to back-angles up to 170°. These data will be analyzed employing the coupled-channel program ECIS79 in terms of vibrational and rotational models.

Other $(\vec{p},p')$ measurements and analyses will be conducted on the isotopes ^{78,80,82,84}Kr as part of this study.

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3. Deuteron-Induced Reactions

a. Tensor Analyzing Powers for the (d,α) Reaction (B. C. Karp, E. J. Ludwig, R. E. Anderson, J. E. Bowsher, T. B. Clegg, R. L. Varner)

It has been shown that tensor analyzing powers for (d,α) reactions are sensitive to the effects of L mixing[1,2] and the α-particle D state.[3] In this study, we intend to isolate these effects. Such a separation can be accomplished by looking at transitions for which other considerations, such as the shell structure, suppress the L mixing. It is hoped that this method will provide an accurate measurement of the D-state component of the α-particle wave function.

We have measured angular distributions for iT_{11}, T_{20}, T_{22}, and $\frac{d\sigma}{d\Omega}$ for the ^{28}Si(d,α)^{26}Al reaction at 16 and 13.5 MeV and for the ^{89}Y(d,α)^{87}Sr reaction at 12 MeV. The ^{26}Al ground state has $J^\pi = 5^+$ and thus provides a case where L mixing should be suppressed since L=6 contributions must come from a higher shell. Also, the 1/2$^-$ first excited state of ^{87}Sr is populated mainly[4] by L=0, J=1 and is expected to be quite sensitive to the α-particle D state. In contrast, L mixing may be important for several of the other states populated by these reactions.

A better understanding of the systematics can be obtained by taking data over a range of energies. In particular, measurements taken near or below the Coulomb barrier should be insensitive to the optical potential. In the case of the ^{28}Si experiment, compound nucleus contributions precluded our using beam energies much below 13.5 MeV. For the ^{89}Y$(\vec{d},\alpha)$ reaction, we plan to make additional measurements at 16 MeV and at a lower energy such as 9 MeV.

Additionally, unpolarized and vector-polarized excitation functions have been measured for the ^{28}Si(d,α) reaction from 11.5-15.0 MeV in 100-keV steps. Unpolarized angular distributions at 5, 6, 7, 8, and 10 MeV, and vector-polarized excitation functions between 5 and 7 MeV in approximately 200-keV steps have been measured for the ^{89}Y(d,α) reaction. The purpose of these measurements is to estimate compound-nucleus contributions and to avoid taking tensor-polarized data in a resonant region. We have also measured (α,α) and $(\vec{d},d)$ scattering in order to obtain good optical potentials for use in the analysis of the tensor data.

Calculations are being performed with the code TWOFNR[5] which can carry out exact finite-range calculations in a second-order Born approximation. Results will be discussed at the fall 1983 Notre Dame meeting of the APS.

b. Investigations of The Reactions ^{58}Ni(d,α)^{56}Co And ^{50}(d,α)^{48}Sc with Vector And Tensor Polarized Deuterons (M. Haller,* W. Kretschmer,* R. E. Anderson, B. L. Burks, T. B. Clegg, H. J. Ludwig, R. L. Varner, J. F. Wilkerson)

Angular distributions of cross section, vector and tensor analyzing powers have been measured for the reactions ^{58}Ni$(\vec{d},\alpha)^{56}$Co and ^{50}Ti$(\vec{d},\alpha)^{48}$Sc at $E_d = 16$ MeV. The vector analyzing power A_y of (d,α) reactions proved to be very sensitive to the transferred angular momenta L and J. Patterns of experimental values of A_y allow clear J^π assignments of the final states. A good DWBA description of the experimental data could be achieved by observing a matching condition. This condition demands an equal geometry in the real parts of the optical potentials in the entrance and exit channel ($r_0(\alpha) = r_0(d)$, $a_0(\alpha) = a_0(d)$) and the depth of the α potential to about twice the depth of the deuteron potential. This condition, together with the requirement of a good description of the elastic scattering in the deuteron and α-channels by the optical potentials, reduces the large parameter space of direct reactions and simultaneously leads to a quite good DWBA description of all observables. In this way, the importance of the matching condition has been extended to the description of polarization data.

Fig. D3-1 demonstrates the sensitivity of A_y to the

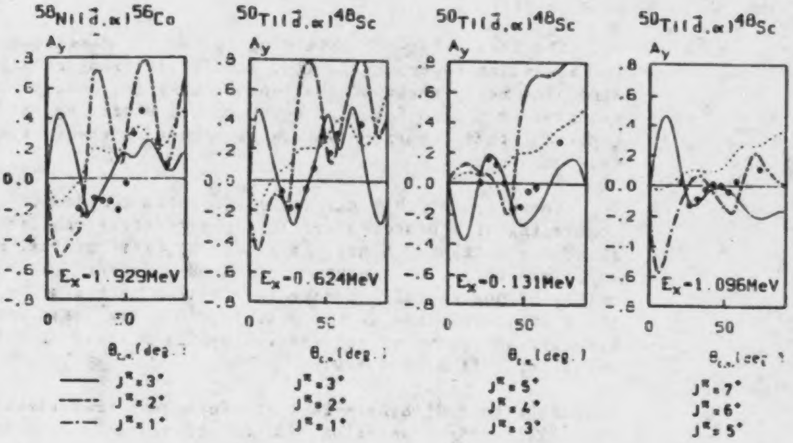

Fig. D3-1. Calculations and data for A_y for alternative J transfers. Values for J other than the proposed value can be ruled out definitively.

transferred J values. Calculations for alternative J values, all other parmeters being unchanged, are compared with experimental data. In all cases, J values other than the proposed J values can be ruled out definitively, which verifies the usefulness of ($\vec{d}$,α) reactions for nuclear spectroscopy.

This work has been submitted to Nuclear Physics.

c. The (d,^{6}Li) Reaction Induced by Tensor-Polarized Deuterons (J. E. Bowsher, E. J. Ludwig, T. B. Clegg, B. C. Karp, R. L. Varner)

A preliminary investigation of the reaction ^{40}Ca(d,^{6}Li)^{36}Ar(g.s.) has been made with a beam energy of 17 MeV. The cross-section has been measured from 20° to 90° in 5° steps.

The feasibility of obtaining an angular distribution of the analyzing powers iT11, T20, and T22 is being studied. Since the measurement of the tensor analyzing powers requires an 8-step sequence for each angle setting, it is important that the proposed reaction have an adequate cross section.

To an extent, ^{6}Li has a wave function component consisting of a deuteron and an alpha particle orbiting about one another. Since ^{6}Li has $J^{\pi}=1^{+}$, this orbital motion may, in general, be a mixture of S and D states. The tensor analyzing powers will provide information on the strength of the D state relative to the S state. Similar measurements have already provided information on the D state of the deuteron, helion, and triton.

d. Investigations of Single-Particle-Forbidden Transitions in The ^{48}Ti($\vec{d}$,t)^{47}Ti Reaction (R. E. Anderson, C. A. Patty, T. B. Clegg, B. C. Karp, E. J. Ludwig, and R. L. Varner)

Cross sections and vector analyzing powers have been measured for approximately 15 states in ^{47}Ti populated by the ^{48}Ti($\vec{d}$,t) reaction at 16 MeV. The outgoing tritons were detected with ΔE-E telescopes of silicon surface-barrier detectors and a resolution of about 45 keV FWHM was obtained. Fig. D3-2 shows a sample (d,t) spectrum. Many of these states, such as the $9/2^{-}$ at 1.25 MeV and the 1.45-MeV $11/2^{-}$ state, should not be populated if the reaction proceeds as a direct one-step neutron pickup from the target nucleus. Presumably, two-step contributions are responsible for most or all of the observed cross section.

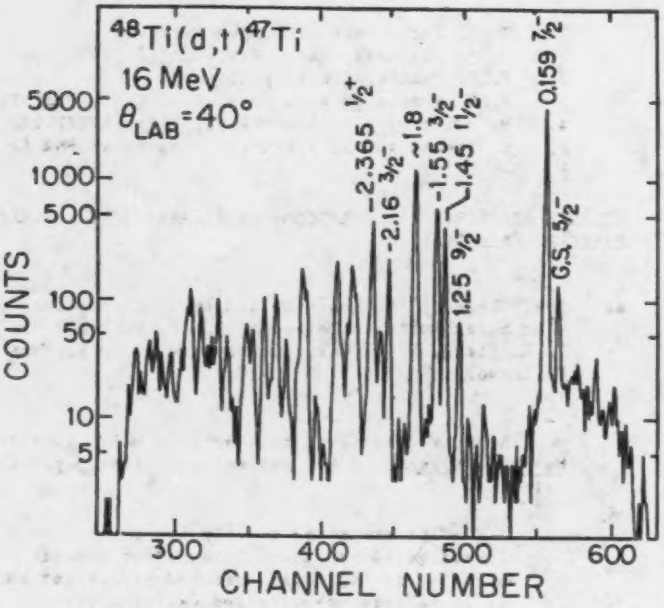

Fig. D3-2. A sample spectrum for the ^{48}Ti(d,t)^{47}Ti reaction.

The goal of this work, then, is to understand the reaction mechanism and, in particular, the two-step effects. Coupled-channels calculations are being performed with the code CHUCK2. The analyzing powers of the strongly populated single-particle states are being used to constrain the calculations. Preliminary results show the experimental data, for the most part, being reasonbly well produced.

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4. Nuclear Spectroscopic Measurements Related to the Design of Solar Neutrino Detectors

a. The $^{80}\mathrm{Kr}(\vec{d},p)^{81}\mathrm{Kr}$ Reaction and Implications for Design of a $^{81}\mathrm{Br}$ Solar Neutrino Detector (B. L. Burks, R. E. Anderson, T. B. Clegg, B. C. Karp, E. J. Ludwig, R. L. Varner, J. F. Wilkerson)

A paper describing this work is being submitted to Nuclear Physics. A brief summary of that paper is given below:

> "The structure of ^{81}Kr has been investigated via the $^{80}\mathrm{Kr}(\vec{d},p)^{81}\mathrm{Kr}$ reaction using an isotopically enriched gas target and an 11 MeV vector-polarized deuteron beam. Differential cross sections and vector analyzing powers have been measured from 25 degrees to 85 degrees for proton groups leading to 17 states below 2.5 MeV in excitation. An ion-implanted target was used for measurements at additional angles including 20 degrees. Comparisons of these distributions to DWBA calculations were made to extract spectroscopic factors and values of spin (J) and parity (π) for these states.
>
> The gas target was 93% enriched in ^{80}Kr and experimental resolution was about 65 keV FWHM. The ion-implanted target was 0.023 mg/cm^2 thick in ^{80}Kr, resulting in an experimental resolution of about 30 keV FWHM. Rutherford scattering at 6.0 MeV provided a reference for absolute measurement of the cross sections to within a 5% uncertainty. The total uncertainty in absolute (d,p) cross sections considering

counting statistics, background subtraction, and overall normalization is typically 15%.

Cross sections and vector analyzing powers were measured for elastic deuteron scattering from the enriched ^{80}Kr gas target over an angular range of 25 degrees to 160 degrees. An optical-model analysis of this data provided the deuteron potential for the DWBA calculations. In a separate experiment, cross sections and vector analyzing powers were measured for proton elastic scattering using the enriched ^{80}Kr gas target and a 16 MeV beam. An optical-model analysis of this data provided the proton potential for use in DWBA calculations. The resulting proton and deuteron optical-model parameters are presented in Table 1.

Table 1

Optical Model Parameters Used in DWBA Calculations

Particle	V	r_0	a_0	W_D	r_w	a_w	V_{so}	r_{so}	a_{so}	r_C
p	49.62	1.24	0.68	10.60	1.23	0.63	5.80	1.03	0.65	1.27
d	92.0	1.20	0.79	20.0	1.27	0.74	4.0	0.70	0.50	1.30

Potential depths are given in MeV, geometrical parameters are given in fm. The parameters are defined according to the notation of Becchetti and Greenlees.[1]

A summary of the spin-parities assigned from the present work is given in Table 2 and compared with those found in the Table of Isotopes.[2] The neutron spectroscopic factors extracted in the present work are also listed in Table 2. Five states in ^{81}Kr were identified in the present work with spin-parity appropriate for population by allowed neutrino capture in ^{81}Br. The $1/2^-$ state at 0.190 MeV and $5/2^-$ state at 0.457 MeV should contribute the majority of the observed neutrino capture rate for a ^{81}Br experiment. Two states, at 0.637 MeV and 0.920 MeV, with spin-parity $3/2^-$ could also

> contribute to the observed neutrino capture rate. The $1/2^-$ state at 1.744 MeV can be populated only by capture of the rare, high-energy ^{8}B neutrinos and is therefore not expected to make a significant contribution to the observed capture rate."

Table 2

Summary of Spectroscopic Information for States in ^{81}Kr.

E(MeV)	Jπ		S_γ
	this work	Table of Isotopes (reference 2)	
0.050	$9/2^+$	$(9/2^+)$	0.25
0.190	$1/2^-$	$1/2^-$	0.25
0.457	$5/2^-$	$5/2,3/2^+$	0.36
0.552	$5/2^+$	$(5/2,3/2^+)$	0.08
0.637	$3/2^-$	$(3/2)^-$	0.07
0.732	$5/2^+$		0.02
0.920	$3/2^-$	$(1/2,3/2^+)$	0.04
0.980	$1/2^+$	$(1/2^+)$	0.16
1.098	$3/2^+$	$(5/2,3/2^+)$	0.19
1.281	$5/2^+$	$(5/2,3/2^+)$	0.04
1.492	$1/2^+$	$(3/2,1/2)^-$	0.04
1.678	$9/2^+$	$(5/2,3/2)^-$	0.17
1.744	$1/2^-$		0.04
1.888	$5/2^+$		0.03
2.218	$5/2^+$		0.09
2.380	$1/2^+$		0.03
2.426	$1/2^+$		0.04

b. The ^{86}Sr($\vec{d}$,p)^{87}Sr Reaction And The Implications for Design of A ^{87}Rb Solar Neutrino Detector (B. L. Burks, R. E. Anderson, T. B. Clegg, B. C. Karp, E. J. Ludwig, R. L. Varner)

A paper decribing this work is being submitted to *Nuclear Physics*. A brief summary of that paper is given below:

> "The structure of ^{87}Sr has been investigated via the ^{86}Sr($\vec{d}$,p)^{87}Sr reaction using an isotopically enriched target and an 11 MeV vector-polarized deuteron beam. Differential cross sections and vector

analyzing powers have been measured from 25 degrees to 105 degrees for proton groups leading to 18 states below 4.0 MeV in excitation. Comparisons of these distributions to DWBA calculations were made to extract spectroscopic factors and values of spin (J) and parity (π) for these states.

The target was 97% enriched in ^{86}Sr and experimental resolution was about 42 keV FWHM. Rutherford scattering at 6.0 MeV provided a reference for absolute measurement of the cross sections to within a 5% uncertainty. The total uncertainty in absolute (d,p) cross sections considering counting statistics, background subtraction, and overall normalization is typically 15%. An optical-model analysis of deuteron elastic scattering at 11 MeV was fitted to cross section and vector analyzing power data from 25 degrees to 165 degrees. The resulting optical-model potentials are presented in Table 1 along with proton potentials deduced from proton scattering on an enriched ^{87}Sr target at 20.5 MeV.[3]

Table 1

Optical Model Parameters Used in DWBA Calculations

Particle	V	r_0	a_0	W_D	r_w	a_w	V_{so}	r_{so}	a_{so}	r_C
p	54.37	1.17	0.58	6.66	1.09	1.01	6.78	1.01	0.75	1.27
d	90.3	1.21	0.79	14.20	1.36	0.78	6.90	0.70	0.35	1.30

Potential depths are given in MeV, geometrical parameters are given in fm. The parameters are defined according to the notation of reference.[1]

A summary of spin-parity assignments from the present work is given in Table 2 along with the spectroscopic factors extracted by comparing the measured cross section for each state to the cross section predicted by the DWBA calculations. Two low-lying states in ^{87}Sr were identified with appropriate spin-parity to be populated by allowed neutrino capture in a ^{87}Rb experiment. The $1/2^-$ state at 0.388 MeV should contribute the majority of the observed neutrino capture rate for a ^{87}Rb solar neutrino detector, but the $3/2^-$ state at 0.873 MeV would also contribute significantly to the observed neutrino capture rate."

Table 2

Summary of Spectrocopic Information for States in ^{87}Sr

E(MeV)	J^π		S_γ
		N. D. S. 4	
	this work	adopted levels	
0.0	$9/2^+$	$9/2^+$	0.13
0.388	$1/2^-$	$1/2^-$	0.10
0.873	$3/2^-$	$(3/2)^-$	0.06
1.229	$5/2^+$	$(5/2)^+$	0.08
1.771	$5/2^+$	$(5/2)^+$	0.40
2.170	$1/2^+$	$1/2^+$	0.28
2.681	$3/2^+$	$3/2^+,5/2^+$	0.07
2.82	$9/2^+$		0.09
2.94	$1/2^+$		0.11
3.13	$1/2^+$		0.16
3.17	$3/2^+$	$3/2^+,5/2^+$	0.12
3.28	$5/2^+$	$3/2^+,5/2^+$	0.01
3.39	$5/2^+$		0.03
3.55	$5/2^+$		0.01
3.60	$3/2^+$		0.14
3.67	$3/2^+$		0.05
3.78	$3/2^+$	$3/2^+,5/2^+$	0.03
3.89	$1/2^+$	$1/2^+$	0.09

c. The ^{81}Kr - ^{81}Br Ground State Mass Difference And Calibration of A ^{81}Br Solar Neutrino Detector (B. L. Burks, R. E. Anderson, T. B. Clegg, B. C. Karp, E. J. Ludwig, R. L. Varner)

The majority of the observed neutrino capture rate in a ^{81}Br solar neutrino experiment would be from population of the 0.190 MeV and 0.457 MeV states in ^{81}Kr (see section (a) above). The cross section for neutrino capture in ^{81}Br leading to the 0.457 MeV state is highly uncertain. Therefore, it would be advantageous to calibrate the neutrino capture rate for a ^{81}Br detector. Until the present measurement of the ^{81}Kr - ^{81}Br mass difference, some question existed about the feasibility of using a proposed ^{51}Cr neutrino source for this calibration because the ground state mass excess of ^{81}Kr had large uncertainty.

Energy spectra for the ^{82}Kr(d,t)^{81}Kr and ^{82}Kr(d,^{3}He)^{81}Br reactions were measured simultaneously using E-ΔE detector telescopes and a particle identification data acquisition code. The reactions were induced by 17 MeV deuterons incident upon a 0.09 mg/cm^{2} carbon foil implanted with a dose of 0.03 mg/cm^{2} ^{82}Kr ions and a dose of 0.002 mg/cm^{2} ^{14}N ions at approximately the same depth. Peaks from reactions in the carbon foil and in the ^{14}N implant were used as spectrum energy calibration references.

The Q-values for the two reactions, ^{82}Kr(d,t)^{81}Kr and ^{82}Kr(d,^{3}He)^{81}Br, were compared to determine the ^{81}Kr - ^{81}Br ground state mass difference. The mass difference obtained, 277 + 9 keV, implies that neutrinos from a ^{51}Cr source would populate the 0.457 MeV state in ^{81}Kr by 12 ± 9 keV. Combining the mass difference measured in this work with the reported mass excess for ^{81}Br[2] yields a ground state mass excess for ^{81}Kr of -77699 ± 11 keV. This value for the mass excess of ^{81}Kr differs from the value reported in the Table of Isotopes[2] by 45 keV and differs from the value listed in the mass tables of Wapstra and Bos[5] by 10 keV.

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E. RADIATIVE CAPTURE REACTIONS

1. Status Report (R. August, S. E. King, G. Mitev, J. Riley, N. R. Roberson, D. R. Tilley, D. Wagenaar, M. Whitton, H. R. Weller, M. Wright*)

Much of the effort of the TUNL radiative capture group during the past year has been devoted to capture studies involving few-nucleon systems. Work was done on ^{3}He, ^{3}H and ^{4}He. For the experiments on ^{3}He, a new gas target facility provided a means of obtaining a new level of precision for the angular distribution coefficients. Work done in collaboration with Dr. Don Lehman has shown the sensitivity of these data to D-state effects in the ground state of ^{3}He. The ^{3}H problem was studied via fast neutron capture on deuterium for the very first time. The performance of this experiment required the development of a technique whereby we could detect the recoiling tritons. We have been able to perform this work by employing a deuterated liquid scintillator as a target and requiring a coincidence between the γ-rays and the triton-recoil pulses in this scintillator. The results support previous measurements of both the absolute cross sections and the angular distributions. These data are being analyzed at this time. The comparison of the n+d and p+d data sets emphasizes several interesting features of the 3-body problem which we are trying to understand. We have also obtained polarized $\vec{p}$+d and $\vec{n}$+d capture data which should add to our detailed knowledge of this reaction.

Work has been done in collaboration with Drs. Biedenharn, Delsanto and Danos on the problem of the (γ,p)-to-(γ,n) ratio in ^{4}He and ^{3}He-^{3}H. Our ratios for ^{3}He(γ,p)d-to-^{3}H(γ,n)d cross-sections are close to unity just a few MeV above threshold. This result must be explained along with the ratio of about 1.7 obtained in the ^{4}He case. Although a possible "dynamic Coulomb polarization mechanism" appears, in principle, to be capable of producing these observed ratios, detailed calculations have, to date, been unsuccessful. The mystery remains.

Work on the polarized p+d capture problem has progressed well. Precision data have been obtained for the $\vec{p}$+d case. We have also obtained vector polarized $\vec{d}$+p data at E_d = 2.2 MeV (beam energy). These data, along with the Giessen (Clausnitzer *et al.*) low energy $\vec{p}$+d data are being used to search for M1 strength at 6 MeV in ^{3}He. Higher energy vector and tensor-polarized deuteron capture measurements are underway in a collaborative experiment at McMaster University using their magnetic spectrometer to detect recoiling ^{3}He particles. These results should be sensitive to several aspects of the 3-body problem, such as the presence of the mixed-symmetry state and the D-state in ^3He. Our ultimate goal is to make a detailed comparison of these observables with a full 3-body calculation.

Another problem which has received our attention this year is the study of an apparent secondary-doorway state phenomenon in ^{13}C. This work was done in collaboration with Dr. John Woodworth of Livermore National Laboratory, and Dr. Jim Jury of Trent University. Polarized- and unpolarized-neutron capture data on ^{12}C have been combined with deuteron capture data on ^{11}B and analyzed using a secondary-doorway state model. The extracted primary-to-secondary doorway interaction matrix element has been compared to a shell-model estimate of this number obtained with the assistance of Dr. Dean Halderson. The excellent agreement supports the conceptual basis of the secondary-doorway-state model. These results emphasize the shortcomings of the DSD model as presently formulated and indicate the need for a more sophisticated capture model which includes intermediate-structure effects.

The past year has also witnessed the design, construction, and installation of a new γ-ray detection system. At present this system consists of two 3"x3" Bismuth Germanate detectors housed in 8" diameter plastic (ND-100) anticoincidence shields. The BGO detectors and the plastic shields are equipped with light-emitting diodes which are pulsed to provide a reference signal for gain stabilization. These detectors were chosen because of their increased efficiency and decreased sensitivity to thermal neutrons as compared to NaI. Performance evaluation and calibration of these detectors is presently underway. Preliminary results suggest ~7% resolution for 15 MeV γ-rays. These detectors will add a new capability to the TUNL capture program, especially in the area of low energy few-nucleon capture reaction studies. The first experiments are expected to begin early in the fall of 1983.

2. Radiative Capture to ^3He

We have continued work on the $^2H(p,\gamma)^3He$ reaction. Our accurate measurements of angular distributions at E_p=6.5, 8.0, 11.0, 15.0 and 16.0 MeV have provided the first photonuclear evidence for D-state effects in the ^3He bound-state wave function. In addition we have studied the $^1H(\vec{d},\gamma)^3He$ reaction at a center-of-target energy of E_d=1.62 MeV.

Our results for the $^2H(p,\gamma)^3He$ reaction have been published recently in Physical Review Letters. The abstract follows:

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> "Angular distributions of the $^2H(p,\gamma)^3He$ reaction have been measured for E_p from 6.5 to 16 MeV. A comparison of the extracted a_2 coefficient with an effective two-body direct calculation indicates a sensitivity to the inclusion of D-state components in the ^3He wave function. These calculations use ^3He bound-state wave functions generated from Faddeev-type equations. The theoretical 3-body ^3He ground state wave functions having D-state probabilities of 5-9% (D_2=-0.224 to -0.236) are consistent with our data."

We have compared the energy dependence of the a_2 coefficients extracted from the angular distributions of cross sections for the present work, as well as those from Refs. 1-3, to effective 2-body calculations as shown in Fig. E2-1. The

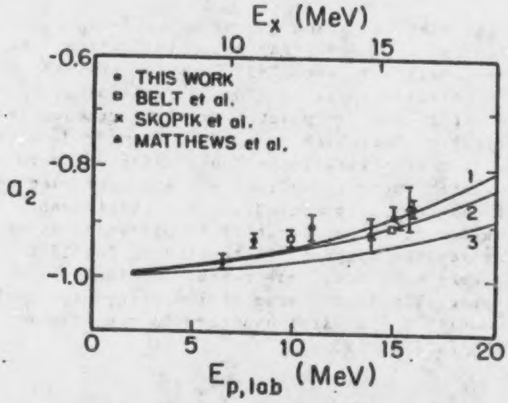

Fig. E2-1. The angular-distribution a_2 coefficients are shown as a function of proton bombarding and excitation energies. Data from the present work and Refs. 1, 2, and 3 are shown with statistical errors. The curves are the results of a direct-capture calculation including E1, E2, and E3 radiation and using Lehman and Gibson's ^3He wave functions. Curves 1, 2, and 3 assume 7, 4, and 0% deuteron D-state probability respectively in the calculation of the ^3He bound state.

curves in Fig. E2-1 are direct radiative capture calculations using the wave functions of Gibson and Lehman[4] for the the final bound state of ^{3}He. These authors[4] generated momentum-space three-body ^{3}He ground-state wave functions from Faddeev-type equations using $^1S_0$ and $^3S_1$-$^3D_1$ separable interactions which fitted the low energy two-nucleon properties. The D-state contribution in these wave functions is put into the model in the form of the D-state probability in the deuteron. The two-body (p+d) wave functions needed for the present calculation were projected out of these three-body wave functions by Lehman.[5] The initial continuum wave function was obtained from the optical model potential which describes the elastic scattering of neutrons from deuterons in this energy region.[6] The direct capture calculation with 100% S-state in the ^{3}He wave function, (Fig. E2-1, curve 3) does not account for the energy dependence of the a_2 coefficients. However, inclusion of a 4 to 7% deuteron D-state probability in the calculation of the ^{3}He wave function gives good agreement with the observed a_2 coefficients. This corresponds to an introduction of 5-9% D-state probability in the ^{3}He wave function (or a D_2 of -0.224 to -0.236). The D_2 parameter is approximately proportional to the ratio of the asymptotic normalization constants of the D-to-S state wave functions.[4] Previous analyses[7] have implicitly attributed the discrepancy in a_2 with respect to the 0% D-state prediction to the presence of E2 radiation and have produced anomalously large E2 cross sections. However, the present calculations have shown that the D-state component in ^{3}He is able to account for the observed a_2 values. D-state presence would correspond to including $S=3/2$, E1 amplitudes in the analyses of Ref. 7.

We have measured the $^1H(\vec{d},\gamma)^3He$ reaction with vector-polarized deuterons at the center-of-target energy of $E_d=1.62$ MeV ($E_x = 6.0$ MeV). The angular-distribution coefficients for cross section and analyzing power were extracted from the data and are given in Table E2-1. In addition we have extracted b_k coefficients from the $^2H(\vec{p},\gamma)^3He$ analyzing powers of Clausnitzer[10] using our angular distribution of cross sections. These results are also given in the table. Two constraints are imposed on the angular distribution of cross section from earlier determinations of the fore-aft asymmetries and the isotropic contribution of the cross sections. The isotropic contribution must equal the measurement of Griffiths *et al.*,[8] and the fore-aft asymmetry was constrained to the value extrapolated from the measurements of Wolfli *et al.*[9] at slightly higher energies. The analyzing-power measurements for both the present (d,γ) reaction and the analyzing powers for the $^2H(\vec{p},\gamma)^3He$ reaction measured by Clausnitzer[10] are shown in Fig. E2-2.

Table E2-1.

Angular distribution coefficients for the cross section and analyzing power of the $^1H(\vec{d},\gamma)^3He$ reaction and for the analyzing power of the $^2H(\vec{p},\gamma)^3He$ ratio at E_x = 6.0 MeV. All center-of-mass angular distribution coefficients are in terms of the γ-ray angles relative to the proton.

	$^1H(d,\gamma)^3He$				$^2H(p,\gamma)^3He$
a_1	0.042 ± 0.018	b_1	−0.006 ± 0.045	b_1	0.08 ± 0.007
a_2	−0.963 ± 0.018	b_2	0.018 ± 0.036	b_2	−0.005 ± 0.006
a_3	−0.070 ± 0.028	b_3	−0.018 ± 0.036	b_3	−0.006 ± 0.006
a_4	0.00 ± 0.05			b_4	−0.001 ± 0.006

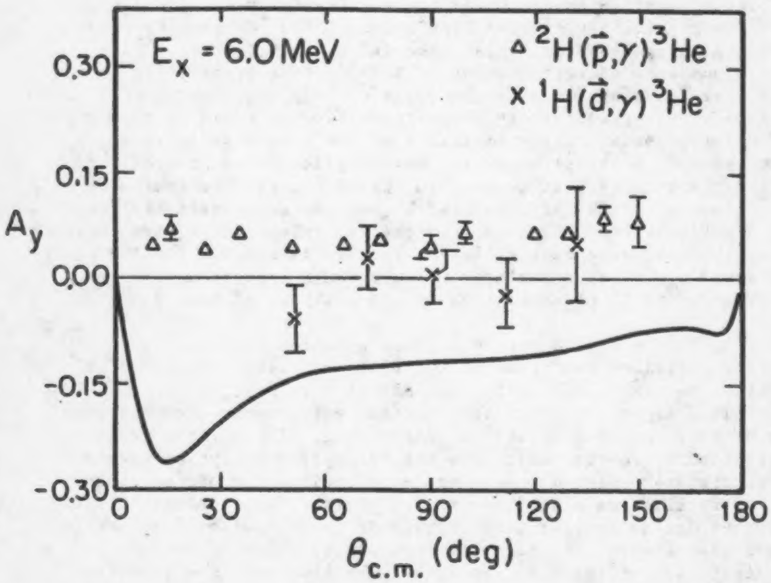

Fig. E2-2. Analyzing power at E_x=6.0 MeV for the $^2H(\vec{p},\gamma)^3He$ reaction of Clausnitzer[10] and the present $^1H(\vec{d},\gamma)^3He$ measurements as a function of lab angles. The solid line is a prediction of the deuteron capture analyzing power based on the $(\vec{p},\gamma)$ data and assuming only S=1/2 transition amplitudes contribute to the reaction.

The relationship between the b_k coefficients obtained in the $^2H(\vec{p},\gamma)^3He$ reaction to those obtained in the $^1H(\vec{d},\gamma)^3He$ reaction when both are measured with vector-polarized beams makes a comparison of the two sensitive to the presence of channel spin $S=3/2$ terms. In particular the ratio of $b_k(\vec{d},\gamma)/b_k(\vec{p},\gamma)$ for terms including only $S=1/2$ (pure doublet) transitions is -3, for $S=3/2$ (pure quartet) terms the factor is 1.5, and for doublet-quartet interference terms the factor is 0.75. The line shown in Fig. E2-2 is a prediction of the $(\vec{d},\gamma)$ analyzing power based on the $(\vec{p},\gamma)$ results assuming pure channel-spin $S=1/2$ transition amplitudes. The measured deuteron-capture analyzing powers are not in agreement with the curve and clearly establish the presence of $S=3/2$ strength.

Since the b_1 coefficient from the $^2H(\vec{p},\gamma)^3He$ reaction is the only b coefficient definitely non-zero, non-E1 radiation must be present. The two most likely candidates for the non-E1 transitions are E2 and M1 terms. Since the E2 strength must arise from d-wave capture, M1 radiation seems more favorable, arising from s-wave capture. It is not possible to extract the M1 contribution in a model-independent transition matrix analysis of this data since there are 16 real amplitudes and 15 relative phases if only E1, E2 and M1 transitions are considered. However with several assumptions based on the direct-capture calculations, our fit of a simplified transition-matrix analysis to the angular distributions of cross section and both $^2H(\vec{p},\gamma)^3He$[10] and $^1H(\vec{d},\gamma)^3He$ analyzing powers indicated the presence of a 1 to 8% M1 contribution (90% confidence limit) to the total cross section. Further analysis of this problem is underway.

REFERENCES (Section E2)

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3. The $^2H(\vec{n},\gamma)^3H$ Reaction

a. New Cross Section And Analyzing Power Data

A polarized angular distribution at $E_n = 9.0$ MeV and an unpolarized yield point at $E_n = 6.85$ MeV have been measured as part of the study of the mass-three system through the reaction $^2H(n,\gamma)^3H$. These experiments have required the use of a deuterated liquid scintillator as target. An RCA 8575 photomultiplier tube views the NE232 scintillator through a connecting 3" lucite light pipe. Backgrounds in the NaI detectors have been substantially reduced by requiring a coincidence between pulses from the γ-ray detectors and pulses from the scintillator.

A new feature added to the apparatus has been a light emitting diode which is connected via a fiber optic cable to the scintillator light pipe and points down into the phototube. The LED is driven by a pulser at a frequency of approximately 1 kHz. This signal can be allowed to appear in the scintillator recoil spectrum enabling us to monitor the gain stability of the scintillator and phototube. Detection of triton recoils in this experiment is critical and the ability to monitor the gain of the system insures confidence in the measurement.

In Fig. E3-1 are displayed the analyzing power

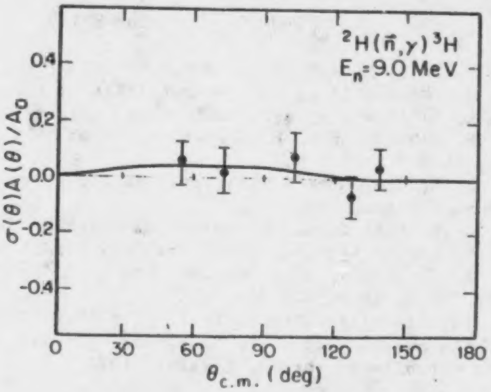

Fig. E3-1. Analyzing power measurements for $^2H(n,\gamma)^3H$.

measurements for a neutron bombarding energy of 9.0 MeV. All of the points represent small values, a result similar to that observed in the proton capture reaction ^{2}H($\vec{p}$,γ)^{3}He.[1] The unpolarized angular distribution at this energy is shown in Fig. E3-2.

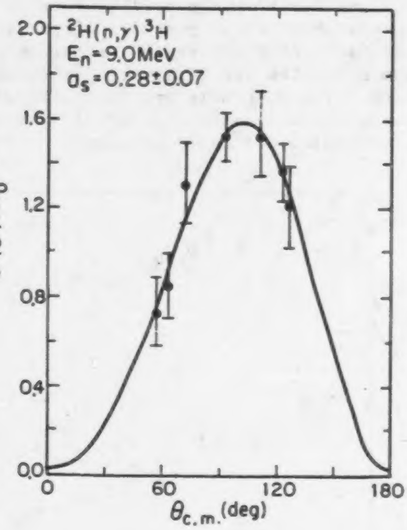

Fig. E3-2. Angular distribution for ^{2}H(n,γ)^{3}H.

These data display a large asymmetry about 90°, a_s = -0.28 ± 0.07. This value for a_s is comparable in magnitude to that of the ^{2}H(p,γ)^{3}He reaction,[1] instead of 5 times smaller as predicted by kinematic effective charge arguments. Although a model independent analysis of the ^{2}H($\vec{n}$,γ)^{3}H data is not practical because of the large number of T-matrix elements, both the small values of the analyzing powers and the large values of the asymmetry provide restrictions for three-body calculations.

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A 90° yield measurement at $E_n = 6.85$ MeV, corresponding to a γ-ray energy of 10.8 MeV, has extended the cross section data closer to the threshold energy of the $^2H(n,\gamma)^3H$ reaction. This measurement shows that the $(\gamma,p)/(\gamma,n)$ cross section ratio in the three-body system remains unity as threshold energy is approached from above, a result different from that observed in the four-body system.[2] Skopik[3] and Faul[4] obtain similar results in measurements of the inverse reactions, photodisintegration of ^3He and ^3H. In Fig. E3-3 are displayed 90° cross section ratios for the three body system and total cross sections for the $^3H(\gamma,n)^2H$ reaction. The TUNL data are the only existing capture data and have been converted via detail balancing to photodisintegration cross sections.

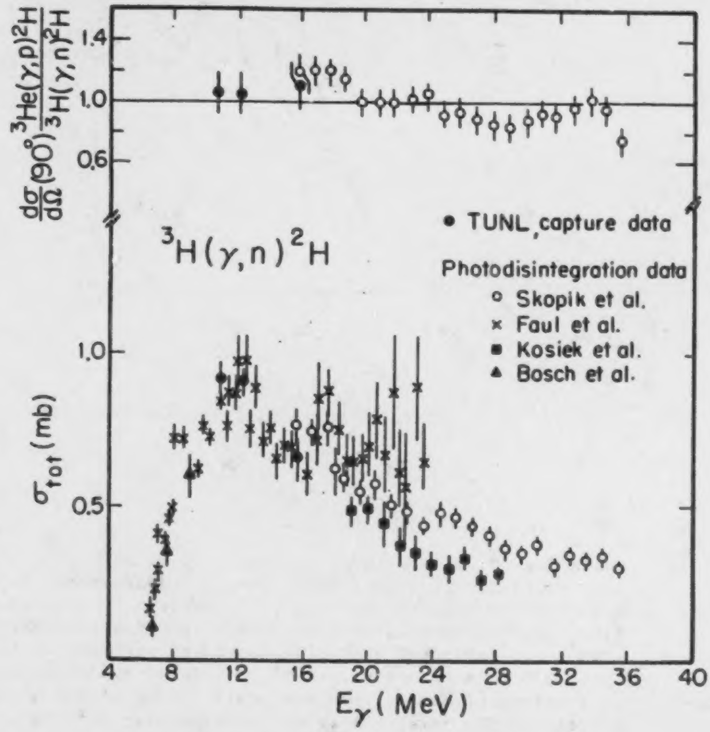

Fig. E3-3. $^3He(\gamma,p)^2H/^3H(\gamma,n)^2H$ 90° cross section ratios and $^3H(\gamma,n)^2H$ total cross section measurements.

REFERENCES (Section E3a)

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b. Relative Response of the Deuterated Liquid Scintillator NE232 to Tritons

A letter to the editor has been submitted to the journal _Nuclear Instruments and Methods_. The abstract is as follows:

> "Light output for recoiling tritons at six energies from 2.3 to 4.1 MeV relative to recoiling 6.1 MeV deuterons has been measured and compared to a semi-empirical calculation."

The deuterated liquid scintillator NE232 has been employed as a target in the $^2H(\vec{n},\gamma)^3H$ reaction. Coincidences between the γ-ray detectors and the scintillator have been used to reduce backgrounds in the γ-ray spectra. Furthermore, we have been able to observe the relative response of the scintillator to tritons. Theoretical work by Birks[1] and Chou[2] has led to a two-parameter semi-empirical equation which expresses the light output of a stopping charged particle in terms of its specific energy loss dE/dx. We have employed the parameters measured by Craun and Smith[3] in our calculation. In Fig. E3-4 are displayed our triton data along with the normalized fit to the six points. The triton recoils, which must be in coincidence with $^2H(n,\gamma)^3H$ γ-rays, are mono-energetic and form definite peaks with noteable centroids. The deuteron recoils, resulting primarily from elastic scattering of incident neutrons, are not mono-energetic. Our best determination of the position of the maximum energy deuteron recoils (E_d = 6.1 MeV) is represented by the shaded region with spread comparable to the distinct triton peaks. The same normalization coefficient used in fitting the triton data was used in calculating the curve for deuterons.

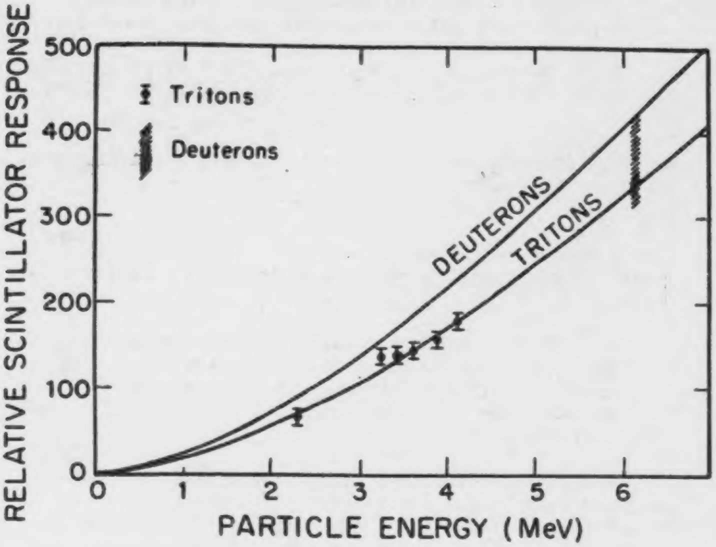

Fig. E3-4. NE232 scintillator response for tritons relative to deuterons.

We have measured the first data for relative response of tritons in a scintillator. Considering the uncertainties involved in the parametric calculation as well as the uncertainties associated with the location of the deuterons and tritons, the agreement between predicted and observed response of the tritons relative to 6.1 MeV deuterons seems quite good.

REFERENCES (Section E3b)

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4. The $^1H(\vec{d},\gamma)^3He$ Reaction at $E_d = 19.5$ MeV (Performed at McMaster University with J. Kuehner)

A collaborative effort to measure the vector and tensor analyzing powers for the $^1H(\vec{d},\gamma)^3He$ reaction has been initiated at McMaster University. A 19.5 MeV polarized-deuteron beam is used along with a 300 μg/cm^2 CH_2 target and the recoiling ^3He ions are detected in the McMaster Enge split-pole magnetic spectrometer using a two-chamber proportional counter. The spectrometer is set at zero degrees for this measurement. Since the recoiling ^3He ions are emitted between 0° and 3.5°, a single position spectrum of the ^3He ions is equivalent to a γ-ray angular distribution. Preliminary runs have produced excellent mass separation of d, ^3He and α's and clean ^3He position spectra. A complete set of measurements aimed at determining the a, b, c, d and e coefficients[1] from vector and tensor polarized beams is planned. Measurements having high statistical accuracy will be sought.

REFERENCES (Section E4)

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5. Theoretical Study of The (γ,p)-to-(γ,n) Ratio in ^4He (with L. C. Biedenharn, P. P. Delsanto and M. Danos)

Several continuum shell model (CSM) calculations have been performed in recent years in the framework of the 1p-1h approximation. All of these calculations agree with the result $R(Ex) = 1.08 \pm 0.05$, where R(Ex) is the (γ,p)-to-(γ,n) cross section ratio, in the excitation region of 25 to 35 MeV. Recently, Delsanto *et al.*[1] have found that a reduction of 30-to-50% in the p-p residual matrix element can reproduce the "observed" ratio. This calculation does not, however, answer the basic question of the physical origin of the phenomenon, i.e., whether or not the observed asymmetry is due to some anomalous charge dependence of the nuclear force.

Halderson and Philpott[2] have investigated this question by performing a CSM calculation which included the charge-symmetry breaking (CSB) force phenomenologically deduced to remove discrepancies in the Coulomb energy shifts in mirror nuclei. They conclude that it is highly unlikely that a CSB force can explain the observed R(Ex).

Deuterons have a high probability of being formed, but not of escaping in the energy region between $Q_d = 23.75$ MeV and $Q_{2n2p} = 28.3$ MeV. Loosely bound deuteron-like configurations may therefore be important at these low energies, and they can be easily charge polarized. This could have the effect of keeping protons, on the average, further apart from each other than neutrons. Beyond Q_{2n2p}, the competing process of complete nuclear breakup makes this mechanism less important.

In ^{4}He, the observed asymmetry would then result as a consequence of the interaction between the continuum of quasi-deuteron channels and the one-particle continuum of open channels. This interaction can be treated by extending the Dirac-Fano formalism[1] to the case of two interacting continua. Wavefunctions for the quasi-deuteron configurations were written in the form

$$\chi_{\ell_1\ell_2\ell_3}(\vec{r}_1,\vec{r}_2,\vec{r}_3,\vec{r}_4) = NA\left[r_{12}^{\ell_1}\, e^{-\alpha r_{12}} r_{34}^{\ell_2} e^{-\beta r_{34}} e^{-\gamma\rho} e^{-\tau R_{cm}^2}\right]$$
$$\times \left[\, Y^{\ell_1}(\hat{r}_{12}) \times Y^{\ell_2}(\hat{r}_{34}) \times Y^{\ell_3}(\hat{\rho})\,\right]^{[0]}$$

where r_{12} and r_{34} are the n-p distances in each quasideuteron, ρ is the distance between the centers of mass of the two deuterons, N is a normalization factor, A is the antisymmetrization operator and α, β, γ, τ are suitable constants.

Calculations are presently underway to ascertain the validity of this proposed explanation.

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6. Polarized Deuteron Capture on ^{11}B and ^{13}C

Work on the $^{11}B(\vec{d},\gamma_0)^{13}C$ reaction was undertaken for the purpose of studying a resonance in this reaction[1] which has been identified with a secondary doorway state in ^{13}C during a study of the $^{12}C(n,\gamma_0)^{13}C$ reaction.[2] The ultimate goal is to fit these data simultaneously with the $^{12}C(n,\gamma_0)^{13}C$ data, using an analysis based on the doorway-state formalism of Feshbach, Kerman and Lemmer.[3] Because similar behavior has been observed in the $^{13}C(d,\gamma_0)^{15}N$[4] and $^{11}B(d,\gamma_0)^{13}C$ cross sections near E_d = 2.0 MeV, we have also undertaken a study of the $^{13}C(\vec{d},\gamma_0)^{15}N$ reaction.

Polarized deuteron beams were used to obtain angular distributions for the $^{11}B(\vec{d},\gamma_0)^{13}C$ reaction at E_d = 1.6, 1.8, 2.0 and 4.0 MeV, and for the $^{13}C(\vec{d},\gamma_0)^{15}N$ reaction at E_d = 1.6, 1.8 and 2.2 MeV. The results for the two reactions differed greatly in the b_2 coefficient. In the $^{11}B(\vec{d},\gamma_0)^{13}C$ reaction the resulting b_2's were small, while in the $^{13}C(\vec{d},\gamma_0)^{15}N$ reaction they were comparatively large, as seen in Fig. E6-1. Currently

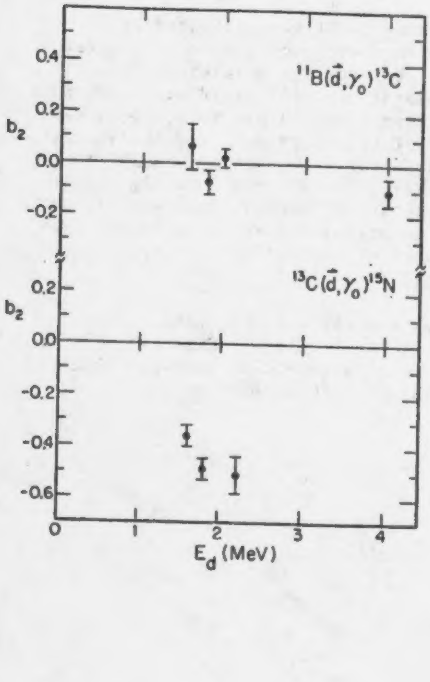

Fig. E6-1. Comparison of the b_2 coefficient of the $^{11}B(\vec{d},\gamma_0)^{13}C$ and $^{13}C(\vec{d},\gamma_0)^{15}N$ reactions.

an analysis is underway considering the process of direct capture to "deuteron like" states in the respective final nuclei of each reaction. It is hoped that this may help explain the large difference in the b_2's. Future work on these reactions will include unpolarized and tensor polarized studies in the regions of these resonances.

REFERENCES (Section E6)

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7. Polarized Neutron Capture on ^{12}C

Work on the $^{12}C(n,\gamma_0)^{13}C$ experiment has continued in collaboration with John Woodworth (Lawrence Livermore National Laboratory) and Jim Jury (Trent University, Peterborough, Ontario, Canada). New data consist of a 90° yield curve, with an average step size of 0.5 MeV, from E_x=10.94 MeV to E_x=21.98 MeV, angular distributions at E_x=17.38 and 21.98 MeV, and the analysis of previously measured polarized data at E_x= 16.02, 18.57, 19.17, 20.09, 21.01, 21.75 and 22.30 MeV. The 90° yield in Fig. E7-1 shows good agreement with previous LANL work.[1] This work is in disagreement in both absolute normalization and in relative peak size from a previous measurement[2] of the 98° yield curve of $^{13}C(\gamma,n_0)^{12}C$ by Woodworth *et al*.

Structure in the a_2 and b_2 coefficients suggests interference with a resonance in the $^{11}B(d,\gamma_0)^{13}C$ reaction.[3] The (d,γ_0) channel was considered to be a secondary doorway[4] which interferes with the primary state in ^{13}C to produce the

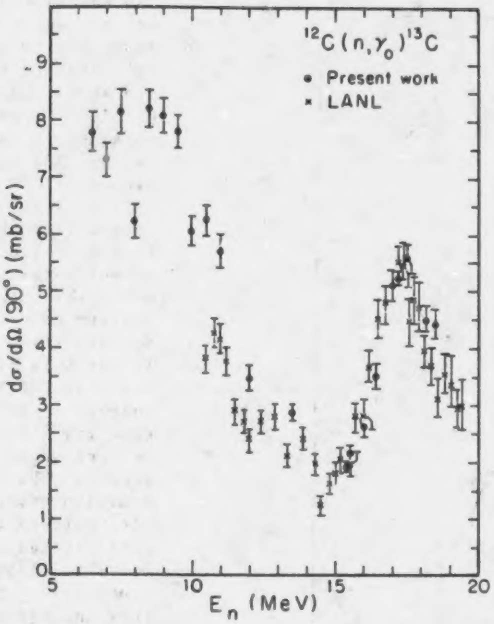

Fig. E7-1. The 90° yield curve for the present work is shown as the solid circles in the figure. The 94° yield curve of Bergqvist is shown as the plus signs in the figure. The upper resonance is the one identified with the primary doorway state in the present work. The absolute scales of each data set were determined independently.

observed structure. An analysis of this structure based on the doorway-state formalism of Feshbach, Kerman, and Lemmer[5] reproduced the features of the data in the region of the structure. Results of this calculation are shown in Fig. E7-2.

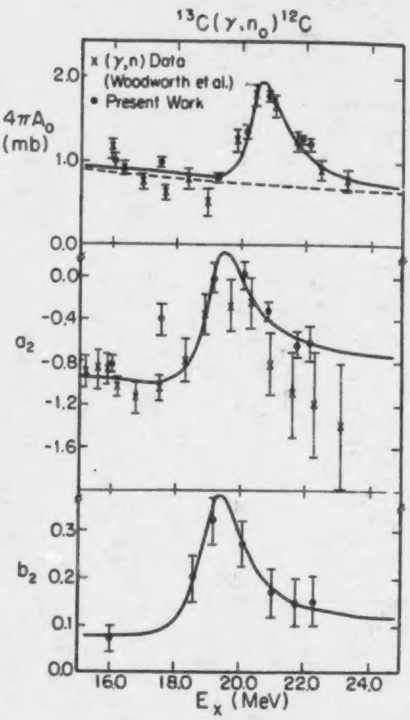

Fig. E7-2. The experimental cross section, angular distribution and polarization coefficients are shown. The solid circles represent data obtained in the present work and the X's represent a reanalysis of the data of Ref. 2, with the A_0 data renormalized by a reduction factor of 1.8. The solid curves correspond to a fit using the interfering primary and secondary doorway state model of Ref. 3. In this fit, the energy and width of the secondary doorway state were taken from the $^{11}B(d,\gamma_0)^{13}C$ capture cross section of Ref. 3. The A_0 and a_2 data from the present work were not included in the fit, but were plotted (after detailed-balancing the cross sections) on the figure to show the agreement with the fit and the previous $^{13}C(\gamma,n_0)^{12}C$ data.

The analysis produced an interaction matrix element $|V| = 720$ keV. It was found that this value could be changed by ± 45 keV without destroying the quality of the fit (χ^2).

In the context of the particle-hole model, the primary doorway state in the $^{12}C(n,\gamma)^{13}C$ reaction would be a 2p-1h configuration. The next step in the particle-hole heirarchy would be the excitation of 3p-2h configurations. These presumably constitute the secondary doorway state. In this picture the coupling between the primary and secondary doorways should represent the shell model matrix element between the 2p-1h and 3p-2h configurations. To be physically consistent with the semidirect model of the reaction, the coupling order was chosen so that the particle-hole pair (in ^{12}C) could be coupled together to form a 1^- T=1 state. The matrix element can be broken down in terms of the two-particle matrix elements by means of straightforward recoupling algebra.[6,7] The two particle shell model matrix elements (G-matrix elements) have been evaluated by Dean Halderson[8] using the two-body interaction of Bertsch et al.[9] Using these to evaluate the appropriate 2p1h-3p2h matrix elements results in an average matrix element of 0.8 MeV. This result indicates that the coupling interaction extracted from the data is of the correct order of magnitude to be that which would be expected for a 2p1h-3p2h matrix element resulting from the strong force.

The present data are presented in a preprint to be submitted to Phys. Rev. C.[10] Future work will consist of the simultaneous analysis of the $^{12}C(n,\gamma)^{13}C$ data with polarized and unpolarized data on the $^{11}B(d,\gamma_0)^{13}C$ reaction in the region of the "secondary doorway state".

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10. J. G. Woodworth, R. A. August, N. R. Roberson, D. R. Tilley, H. R. Weller and J. W. Jury, preprint to be submitted to Phys. Rev. C (1983)

Radiative Capture Reactions

8. The $^{13}C(\vec{n},\gamma_0)^{14}C$ Reaction

During the past year our study of the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction has been completed, and a thesis on this topic has been written by M. C. Wright. A few new measurements of the fore-aft asymmetry have been made since our 1982 annual report, but most of our effort went into data analysis. We have modified our Legendre polynomial fitting codes to allow fitting the a_k and b_k coefficients subject to external constraints. This allowed us to generate a_k and b_k coefficients from the measured angular distributions which are consistent with our more extensive fore-aft asymmetry (a_s) and 90° analyzing power ($A(90^\circ)$) measurements. As an example, the fits to the angular distributions of cross section were subject to the constraint,

$$a_s = 0.5773a_1 - 0.3849a_3 \quad ,$$

where a_s is the measured value of the fore-aft asymmetry. The error of a_s was allowed to contribute to the errors of the a_k coefficients. The b_k coefficients were determined in a similar manner.

An interesting feature of our data is the evidence for two narrow resonances at $E_x(E_n)$=16.7(9.2) and 17.5(10.0) MeV. This is seen most clearly in the $A(90^\circ)$ yield curve shown in Fig. E8-1. The values of a_s are given in Fig. E8-2.

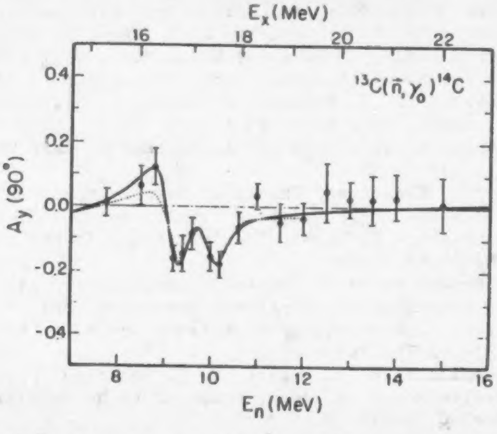

Fig. E8-1. The $A(90^\circ)$ data for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The solid lines are the result of a DSD calculation including two isovector M1 resonances. The dashed curve is a DSD calculation including two E2 resonances. The parameters for the two resonances were optimized to fit the $A(90^\circ)$ data.

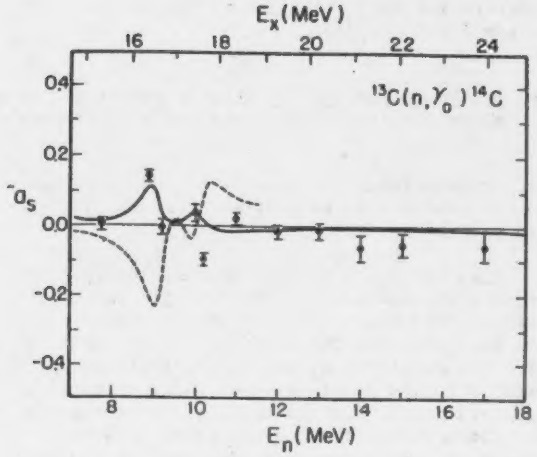

Fig. E8-2. The fore-aft asymmetry data for the $^{13}C(\vec{n},\gamma)^{14}C$ reaction. The curves have the same meaning as Fig. E8-1.

The solid lines in the figures are direct-semidirect model calculations (Code[1] HIKARI) which include M1 resonances at E_x=16.7 and 17.5 MeV with strengths of 0.24 μ_0^2 and 0.17 μ_0^2, respectively. The resonance widths were taken as 200 keV, but the experimental widths are largely due to the 300 keV energy spread of the incident neutron beam. Since the finite values of A(90°) could be due also to E2 strength, we have carried out calculations including two narrow E2 resonances which contain over 50% of the IS EWSR strength. The results are shown as the dashed lines in Figs. E8-1 and E8-2. While the fit to the A(90°) values is almost as good as for two M1's, the a_s fit is significantly worse. This poor fit plus the rather large E2 strengths required by the calculation seem to rule out an E2 interpretation. Our data can best be explained by the existance of two M1 resonances near E_x=16.7 and 17.5 MeV.

REFERENCES (Section E8)

1. H. Kitazawa (Tokyo Institute of Technology, Tokyo, Japan) private communication

9. Polarized Triton-Capture on ^{12}C (Performed at Los Alamos National Laboratory with D. M. Drake and S. A. Wender)

A paper describing the results of this work has been accepted for publication in Nuclear Physics. The abstract is presented below.

> "The 90° cross section for the $^{12}C(t,\gamma_0)^{15}N$ reaction was measured for E_t from 2.3 to 6.5 MeV. Polarized and unpolarized angular distribution data were obtained for $E_t = 2.27$, 3.24 and 5.95 MeV. The resulting a_2 and b_2 coefficients are compared to the predictions of a direct capture (cluster) model. This model gives a reasonably good description of the qualitative behavior observed in the experiment, although it predicts an absolute cross section which is an order of magnitude smaller than any observed cross section."

10. Target Spin Effects in Capture Reaction (with R. G. Seyler, Ohio State Univ., and R. Moreh, Nuclear Resarch Center, Negev, Israel)

A study of the effects of target spin on angular distributions in direct-semidirect reactions has been completed and accepted for publication in Phys. Rev. C. The abstract follows:

> "A recent study of (γ,n_0) reactions on ^{207}Pb and ^{208}Pb produced a direct-semidirect model calculation of the angular distribution (the a_2 coefficient) which was vastly different for these two cases. In this note we offer the formal proof that this is incorrect. It is shown that the angular distribution involving a target with spin is exactly equal to that obtained if the target is treated as spin-zero with the residual spin being the single particle total angular momentum in the final state. A corrected calculation for a_2 is presented for the case of $^{208}Pb(\gamma,n_0)^{207}Pb$ and $^{207}Pb(\gamma,n_0)^{206}Pb$."

11. A New Bismuth Germanate Scintillator Gamma-Ray Spectrometer System

We have recently installed a new gamma-ray spectrometer system, shown diagramatically in Fig. E11-1, which employs a pair

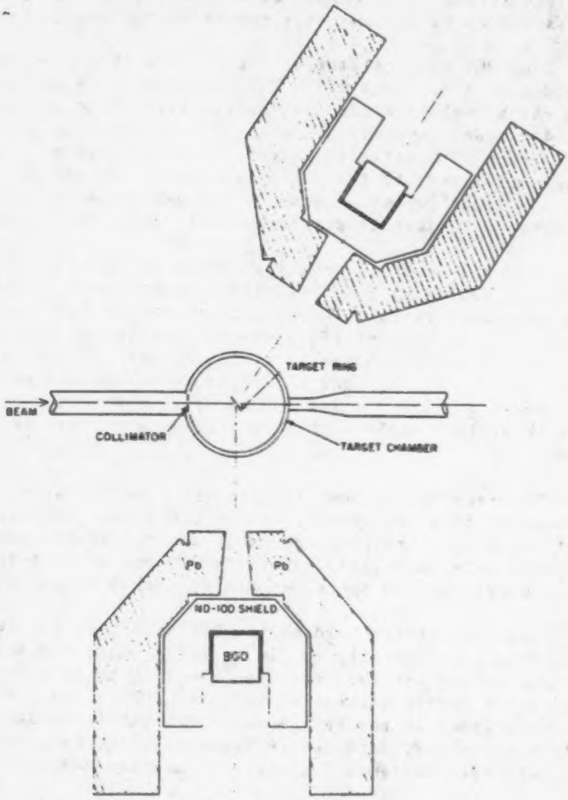
TARGET RING
BEAM
COLLIMATOR
TARGET CHAMBER
Pb
Pb
ND-100 SHIELD
BGO

Fig. E11-1. The new BGO spectrometer.

of 7.62 x 7.62 cm bismuth germanate (BGO) scintillators surrounded in front and on the sides by an anti-coincidence shield of ND-100 plastic. The advantages of BGO scintillators as gamma-ray detectors compared with equal volume NaI scintillators are that: (1) the BGO has a higher full energy gamma-ray detection efficiency, (2) BGO is not hygroscopic, (3) BGO has a better gamma-ray-to-thermal-neutron induced background detection ratio, and (4) the BGO systems can be made smaller and therefore are less sensitive to cosmic ray background and less cumbersome than the large NaI spectrometers. A disadvantage of BGO scintillators is the somewhat poorer energy resolution than NaI.

Each BGO scintillator is housed in a thin aluminum can and viewed with a 3.5-inch 9531R EMI phototube. An EMI tube base is used which employs a circuit incorporating transistors across the last 4 dynodes to provide stability at high count rates. An LED light pulse with variable intensity and frequency is transmitted by optical fibers to the photo-cathode of the 9531R. The output from the light pulser is used in conjunction with a Canberra Spectrum Stabilizer to provide overall gain stabilization.

The well-type 5.1 cm thick ND-100 plastic anticoincidence shield is viewed by four RCA 8575 photomultiplier tubes with transistorized bases. The output of the LED light pulser is also transmitted by optical fibers to the shield and has been used for setting the anti-coincidence timing as well as for testing for gain shifts. During runs the light pulses to the shield are switched off. The top and bottom of each detector have 5.1 cm of lead shielding, while a 10.2 cm thickness of lead shields the sides.

The zero-degree beam leg (target room 4) was rebuilt to accomodate this new system. A new CVC 4-inch diffusion pumping station, a cold trap, vacuum gauge and associated beam pipes and supports were installed. A six-foot diameter, 3/4-inch steel plate holds the two spectrometers 45-inches above the floor.

Aluminum plates holding the BGO detectors and their lead shielding roll radially to give a solid angle for the back surface of the crystals ranging from 7.60 to 23.1 msr. The angle ranges are 35-145 degrees at the near (23.1 msr) radius, and 20-160 degrees at the far radius. Removable, cylindrical collimator plugs, designed to illuminate the back face of each crystal, were designed for the near and far positions.

The first in-beam measurements using these scintillators were obtained in July, 1983. For this run, one BGO detector was operated with an active anti-coincidence shield while the other was operated as a single crystal scintillator. The primary purpose of these measurements was to obtain the gamma-ray response function and the absolute detection efficiency both for a single BGO scintillator and for one with the active anti-coincidence shield. Radiative capture on tritium and ^{12}C provided the standard gamma-rays.

Fig. E11-2 shows four spectra from the experiment. Cosmic ray rejection of better than 99% was obtained throughout the run. The rejected spectra show the rejection of events in which radiation escaped from the BGO and was detected in the shield, as well as the rejection of cosmic rays. Energy resolution for the

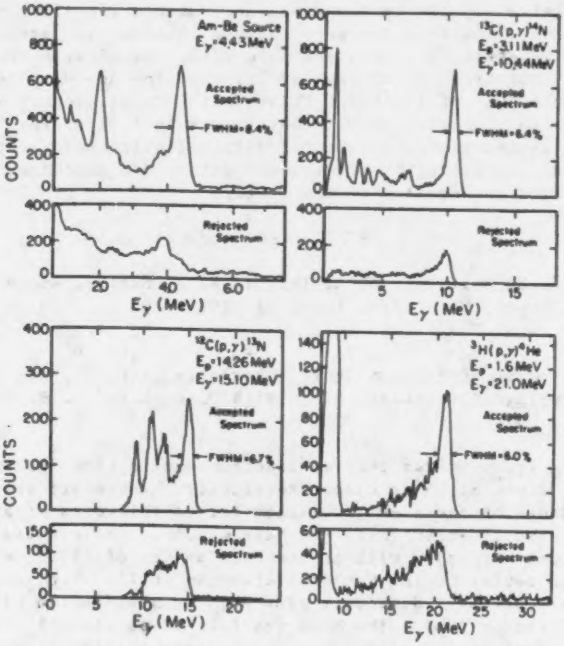

Fig. E11-2. Spectra obtained with the BGO detector.

4.43 MeV gamma ray produced by the Am-Be source was 8.4%. The resolution was 6% (FWHM) for the 21 MeV gamma-ray from the tritium proton capture reaction, a disadvantage of BGO compared with NaI.

The $^{12}C(p,\gamma)^{3}N$ reaction was used to determine the crystal's efficiency. This reaction has an energy resonance near $E_x(E_p)$ = 15.07 (14.24) MeV in ^{13}N. With the detector at 55 degrees, a thick target yield curve gave the number of gamma-rays detected by the BGO. Since the number of gamma rays per proton (6.82 ± 0.22) x 10^{-7}) is well known,[1] the detector efficiency can be calculated. While on the resonance, shield amplifier and discrimination settings were changed in order to determine a curve of efficiency versus shield gain. Finally, a tritium target was used for an angular distribution measurement at a proton energy of 3.0 MeV. These data will be used to make comparisons between results obtained with this system and previous measurements obtained with NaI detectors. Future plans include installing two additional unshielded detectors and finishing calibration of the system.

REFERENCES (Section E11)

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12. Measurement of Tritium Target Thickness Using Elastic Proton Scattering (in collaboration with D. Beck and D. M. Skopik)

A study of the tritium electromagnetic form factors being carried out at Bates Linear Accelerator Laboratory required a knowledge of the average tritium target thickness of a large area tritiated titanium foil. We have measured the elastic scattering reaction $^{3}H(p,p)^{3}H$ with proton beam energy of 13.63 MeV (13.6 MeV at the center of the 5-micron titanium foil). Two solid-state charged-particle detectors were used to measure the yield of scattered protons. The beam was focused on several positions of the target in order to obtain an average tritium target thickness. From the known differential cross sections,[1] the detector solid angles and the integrated beam current, the average tritium content of the target was determined to be 226 $\mu g/cm^2$.[2]

REFERENCES (Section E12)

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13. Large Pauli-Blocking and Virtual Channel Effects in Proton Radiative Capture (L. D. Ludeking, S. R. Cotanch)

A theoretical study involving a coupled channels analysis of $^{11}B(p,\gamma_0)^{12}C$ has been carried out and the results have been accepted for publication in Physics Review Letters. The abstract follows:

> "The photonuclear reaction $^{11}B(p,\gamma_0)^{12}C$ is analyzed within a coupled-channels framework based on a continuum shell model formulation. The microscopic description includes realistic shell model density amplitudes, Pauli-blocking effects, and a large number of nucleon + A=11 open and closed (virtual) channels. Both Pauli corrections and virtual channel contributions are found to be sizeable for energies spanning the giant dipole resonance and improved, but not detailed, agreement is obtained with experiment. The sensitivity of the theoretical E1 cross section to model interactions is documented and discussed."

These results are shown in Figs. E13-1 - E13-4. These data are from Collins *et al.*[1]

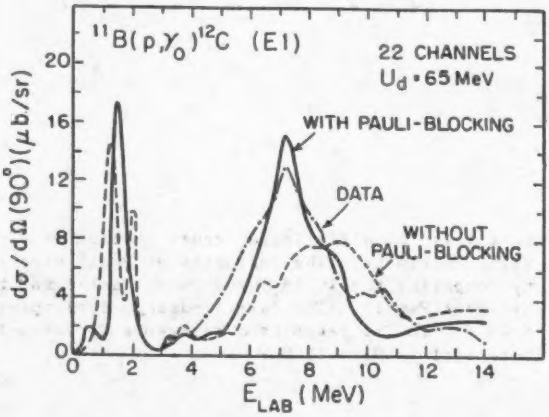

Fig. E13-1. Calculated E1 differential cross section at $\theta = 90^\circ$ compared with experiment. The influence of Pauli blocking can be seen by comparing the solid curve (with Pauli) and the dashed curve (without Pauli). The data (.-dash curve) spans the energies 4-14 MeV and is taken from reference 1. Here the d-wave potential is U_d = 65 MeV.

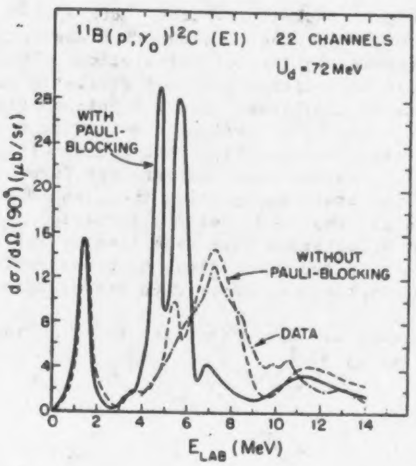

Fig. E13-2. Calculated E1 differential cross section at $\theta = 90^\circ$ compared with experiment. The influence of Pauli blocking can be seen by comparing the solid curve (with Pauli) and the dashed curve (without Pauli). The data (.-dash curve) spans the energies 4-14 MeV and is taken from reference 1. Here the d-wave potential is U_d = 72 MeV.

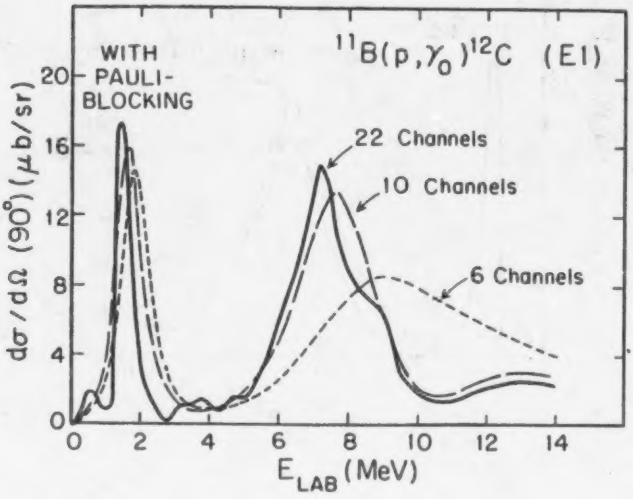

Fig. E13-3. Calculation of $d\sigma 90^{\circ}/d\Omega$ for 6, 10, and 22 channels. Here Pauli blocking has been included and U_d = 65 MeV.

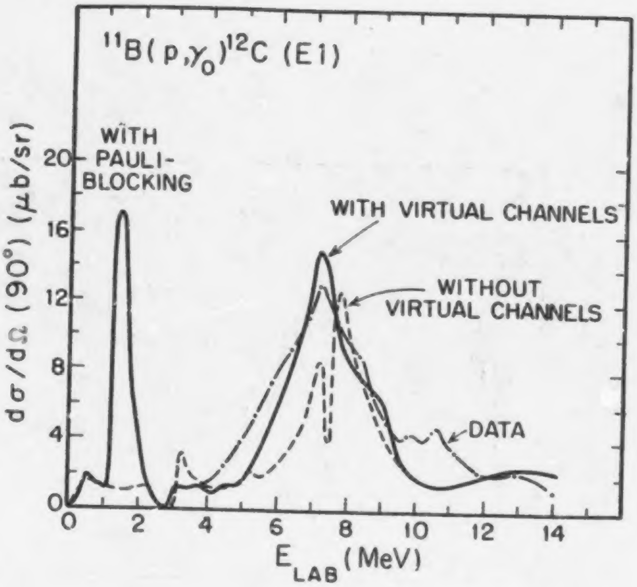

Fig. E13-4. Calculation of E1 differential cross section at $\theta = 90°$ for the same parameters used in Figure 1. The solid curve is the calculation with virtual channels included, whereas the dashed curve is with virtual channels excluded. Again the data (.-dash curve) is from reference 1.

REFERENCES (Section E13)

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F. ACCELERATOR BASED ATOMIC PHYSICS

1. Research Summary (D. Brandt, M. Clark, T. McAbee, J. Swensen, S. M. Shafroth)

From an experimental point of view we were very much encouraged by two three-day runs at TUNL, one in April and one in July, during which we studied Resonant Transfer and Excitation (RTE) and Non-resonant Transfer and Excitation (NTE), via the x-ray charge-changed coincidence method. The projectile was Si^{11+}. Target gases of He, Ne, and Ar were used under single-collision conditions. This was ensured by taking all data at four different pressures including zero, and verifying the linear dependence of count rate on pressure. In all cases Si Kα and Kβ x rays were observed in coincidence with Si^{10+} and Si^{12+}, and for Ne and Ar coincidences were also observed with Si^{9+} and Si^{13+}. In the case of Ar target gas the Ar Kα and Kβ x rays were clearly observed in coincidence with single and double electron capture and loss. In the two TUNL runs we obtained a large amount of data: 1) Single and double electron capture and loss cross sections for the three gases; 2) Si Kα and Si Kβ x-ray yield curves from 20-85 MeV for the three gases; 3) Ar Kα, Kβ and possibly Ne K x ray yield curves over the entire range; 4) All x rays in coincidence with single electron capture and loss. In the case of Ar and Ne there are a significant number of coincidences for projectiles which have gained two electrons and projectile K x rays.

Preliminary analysis indicates that the Si Kα x rays in coincidence with Si^{10+} i.e., electron capture, rises sharply up to 85 MeV which is the highest energy we were able to obtain at TUNL. In principle we should be able to obtain data at up to 95 MeV for Si^{11+} by using charge-state 10 from the tandem accelerator. However up to now there is a problem with the charge state 10 data.

The cross section for RTE is about two times theory at 85 MeV. Fig. F1-1 shows a typical gated x-ray spectrum for 60 MeV Si^{11+} on Ar at 20 mT. Note Si Kα, Kβ and Ar Kα and Kβ. Fig. F1-2 shows the predicted cross section vs projectile energy including NTE and RTE. TUNL data corresponding to the calculations are shown in Fig. F1-3 for Si^{11+} on He. The agreement between theory and experiment, especially the dip in the cross section at about 48 MeV both for theory and experiment, as well as the agreement in absolute cross section is rather convincing evidence that our understanding of the cross section well below the region of the dielectronic resonances is correct.

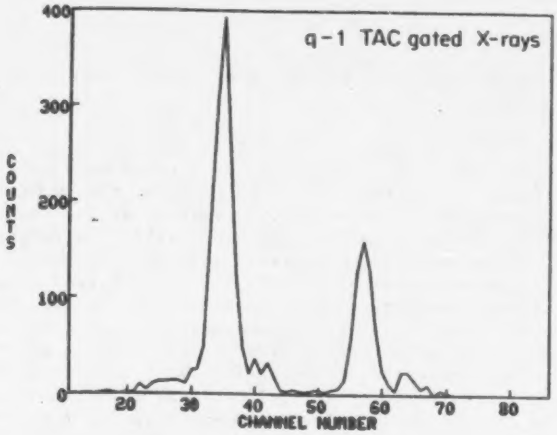

Fig. F1-1. SiK_{α}, SiK_{β}, ArK_{β}, x-rays in coincidence with Si^{11+} projectiles which captured an electron.

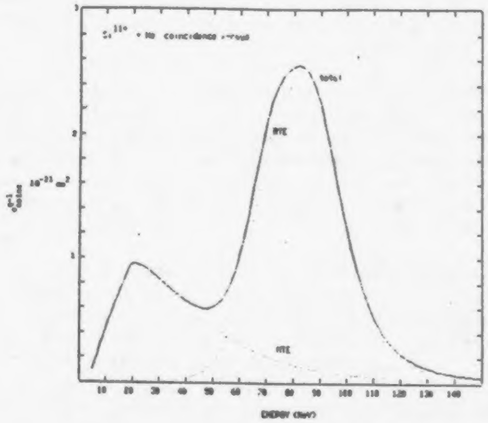

Fig. F1-2. Calculated cross sections for Si K x-rays associated with projectiles which captured an electron due to RTE and NTE.

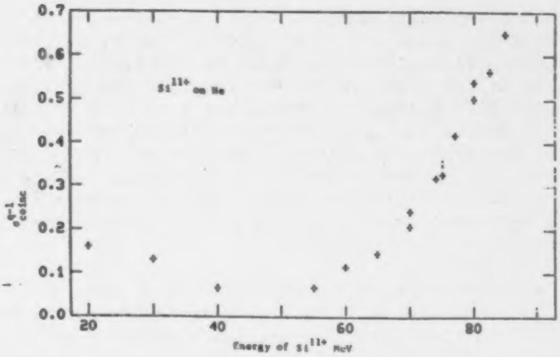

Fig. F1-3. Si K_α x-rays in coincidence with Si^{10+}. Cross sections are 8.46×10^{-21} cm^2 x ordinate. TUNL Data April and July 1983.

i.e., the method of calculating the NTE process is reasonable.

In addition there has been a run at Brookhaven in July, 1983 with Tanis and collaborators, at which Mark Clark from Chapel Hill participated. At Brookhaven, S^{13+} on He was studied from 80 to 150 MeV. The RTE cross section peaked at 120 MeV in agreement with Brandt's calculations. The 120-MeV to 80-MeV cross section was in the ratio of 3 to 1. There are plans to repeat this experiment over a larger energy range and with other target gases and projectiles.

From a theoretical point of view we have also been encouraged by the apparent good agreement between the RTE and NTE calculations of Brandt and experiment. We are also pleased that basic theoretical work is underway at Chapel Hill, where Ms. Reeves is working on the interference between RTE and NTE with Dr. Feagin under the supervision of Professor Merzbacher. Feagin and Reeves have presented a poster on the interference effect at IPEAC, Berlin. Merzbacher, Feagin and Reeves are presenting a theoretical paper at the SESAPS meeting in Nov. 83.

We are still processing data using the new position sensitive parallel plate electron analyzer (PSPPA) to observe the Auger electrons arising from the decay of excited dielectronic recombination states produced via RTE from projectile-ions. The yield of projectile K Auger electrons has been studied using O^{5+} from 15 to 45 MeV on Ar. Individual states are not resolved and a very large background is present. In view of the large background and due to the difficulty of combining spectra taken at different plate voltages Mr. Swensen has designed a new double-pass spectrometer with a rectangular channel plate in the focal plane of the second stage.

Other experiments with the PSPPA have also been undertaken. In particular we have studied the velocity dependence of the production of the $(1s2s2p)^4P^o_{5/2}$ metastable state in collisions of MeV C^{q+}, O^{q+}, and F^{q+} ions with thin carbon foils. We have also studied the foil thickness dependence of this state in oxygen at several ion energies. For different foil thickness, the observed lab energy of the $(1s2s2p)^4P^o_{5/2}$ state decreases with increasing thickness and the width of the peak is seen to increase due to multiple scattering and straggling of the beam in the foil. Figure F1-4 shows two Auger electron spectra of the $^4P^o_{5/2}$ state

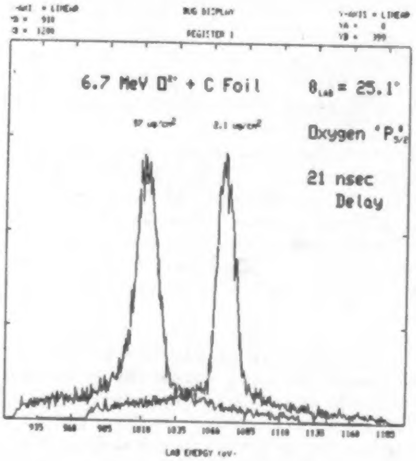

Fig. F1-4. Auger electron spectra of the $^4P^o_{5/2}$ state for 6.7 MeV O^{2+} on C foils of 2.1 and 97 $\mu g/cm^2$.

for 6.7 MeV oxygen, 21 nsec after excitation. This figure illustrates the change in the observed peak energy for the thinnest (2.1 μg/cm^2) and the thickest (97 μg/cm^2) foils.

From the measured line energy and intensity we computed the $^4P^o_{5/2}$ metastable beam fractions for the oxygen system as a function of emergent ion energy (i.e., energy of ion after passage through the foil) and foil thickness. The integrated peak area for the state was corrected for decay-in-flight of the metastable state and for kinematic intensity effects. The results of this study are shown in Fig. F1-5. Here we plot the

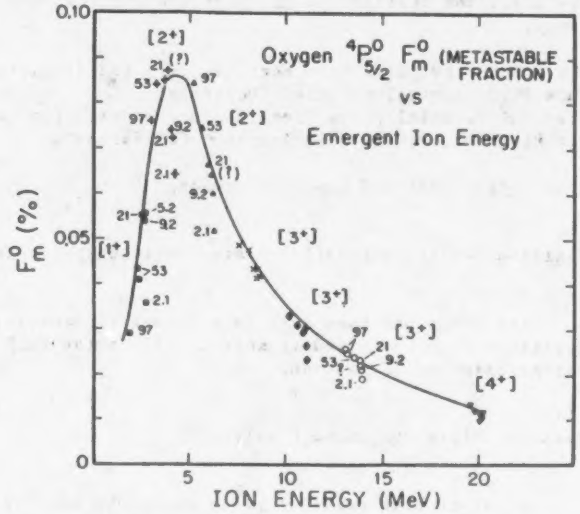

Fig. F1-5. Observed $^4P^o_{5/2}$ percent metastable fraction vs. emergent ion energy.

observed $^4P^o_{5/2}$ percent metastable fraction vs. emergent ion energy. The different groups of points (different plot symbols) represent runs with different incident ion energies. The target foil thicknesses are labeled on the figure where convenient. The quantity in the brackets [q+], q=1-4, near the different groups of data points is the incident charge state of the oxygen ion for that incident ion energy. The curve is drawn only as a guide to the eye. The metastable fraction is seen to maximize near the energy which corresponds approximately to the L-shell velocity for oxygen ($v_L = Z\alpha c/2$). For the thicker foils (≥ 20 μg/cm^2) the metastable fraction is seen to follow the curve. For thinner foils the metastable fraction falls away from this curve to lower values for the metastable fraction. This is presumably due to the fact the emergent average charge state is likely to be closer to the incident charge state, resulting in the production of less Li-like O^{5+} beam of which a fraction of this is the $^4P^o_{5/2}$ state. The incident charge states for this experiment were always less than the predicted equilibrium charge state for that particular ion energy.

These and other data have been analyzed and discussed in Mr. Swenson's Ph.D. thesis, entitled "Development of a Position Sensitive 30° Parallel Plate Electron Spectrometer for The Study of Auger Electrons Produced in Ion-Atom Collisions".

2. Equipment Development and Computer Programs

a. Position Sensitive Parallel Plate Electron Spectrometer

The PSPPA has been used in a number of experiments as described in I above and in more detail in the Ph.D. dissertation of J. Swenson.

b. Parallel Plate Avalanche Counters

A set of four parallel plate avalanche counters has been built by M. Clark so that the q±1 and q±2 projectile ion beams can be detected in coincidence with projectile or target x rays. These detectors have several advantages over surface barrier detectors: they are inexpensive to build; they are not subject to radiation damage; and they operate at high counting rates.

c. Miscellaneous Improvements on the 70° Beam Line Used for X Ray Charge Changed Beam Experiments

Two sets of X and Y micrometer-adjustable slits, separated by 1.8 m, are used to determine the beam trajectory and to ensure proper beam focusing conditions.

An improved gas cell has been constructed so that the Si(Li) detector front face can be within 5 mm of the beam axis.

A new 80 mm^2 Si(Li) detector has been purchased for these experiments at TUNL, using funds from the microelectronics project. Its resolution is 180 eV at 6.4 keV.

Several improvements have been made in the data-acquisition programs at TUNL: x-ray spectra gated by time-to-amplitude converter pulses (TACs) are displayed after each run so that on-line data analysis is facilitated; a two dimensional data disply mode is now available.

d. Computer Programs

The BUG program, written by Brandt, has been considerably extended so that RTE cross sections can be calculated for any target gas, including Compton profiles from specific shells of the target gas or the sum of all shells. It can also be calculated for one dielectronic recombination state or for clusters of states or for all states. NTE cross sections can also be evaluated for a variety of projectile ions, but if Brandt's impact parameter dependent electron capture probabilities are to be used, only He gas targets are expected to give satisfactory results. If other impact parameter dependent formulations are used, the BUG program can be used to perform the required numerical integration so as to obtain the cross section for NTE or capture and ionization for example.

e. The Sputter Ion Source

The sputter ion source has been trouble free during last year. It has been opened once to install new cones and new Cs. Beams of Si, F, C, and Li have been extracted.

G. APPLICATIONS

1. Recent Progress in Using The Radioactive Tracer C-11 in Plants

(C. E. Nelson,* J. Fares,** J. D. Goeschl,** B. R. Strain,*** E. G. Bilpuch)

The 4 MeV Van de Graaff accelerator continued to be used for the production of ^{11}C for real-time studies of carbon transport and allocation in plants. These studies were supported by a $300,000 two-year grant from the Division of Environmental Biology of the National Science Foundation. The ^{11}C, in the form of ^{11}CO, is produced via the $^{12}C(^{3}He,^{4}He)^{11}C$ reaction and is transported continuously to the plant growth chambers, located in the Duke University Phytotron, by an enclosed conduit, where it is oxidized to form $^{11}CO_2$.

The installation of methods to continuously produce and study ^{11}C as a radioactive tracer have been completed. This γ emitting isotope is photosynthetically incorporated as $^{11}CO_2$ into intact plant leaves. Using externally positioned pairs of coincidence counters, the carbon is continuously measured as it moves through the plant.

In the past few months, the following observations have been made:

1. Small but abrupt changes in temperature (i.e., $\lesssim 5^{\circ}C$ for 2 min) can cause stoppages of transport which may last up to an hour. This effect differs in various species and may be part of the competitive advantage of velvetleaf (a weed found in cotton) over cotton.

2. Rewatering of moderately stressed plants causes a rapid drop in ^{11}C activity and presumably the concentration of photosynthates in the transport system. Observed within 2 min at the base of the plant, this response propagates upward, reaching the leaves within 10-15 min. This observation has important implications with respect to net productivity and carbon allocation in arid conditions. It is also a key prediction of transport models used to mathematically model carbon flow in plants.

3. Spontaneous stopping and restarting of phloem transport, and slow recovery of phloem transport in plants which have been trimmed or mechanically disturbed has been confirmed. These responses also have important implications in controlling allocation patterns after grazing and other traumas.

Current ^{11}C tracer studies are addressing the questions of allocation and total productivity of herbaceous plants in elevated atmospheric CO_2. All data have not been analyzed, but there apears to be trend toward an immediate increase in allocation of phtosynthates into storage.

Preliminary work has begun to assess the capability of the 4-MeV accelerator to produce adequate amounts of ^{13}N and ^{15}O for both plant (^{13}N) and animal (^{15}O) studies.

The possible use of ^{13}N in this study has been a long term goal of our program to utilize short-lived isotopes. At present, the nuclear reaction available for use using the 4 MeV Van de Graaff accelerator is that of deuterons on $^{12}CO_2$ target gas $^{12}C(d,n)^{13}N$. In preliminary tests we have found, as predicted by its high cross section, that it is a very efficient reaction. However, the deuteron beam also produces high levels of neutrons around the accelerator-target system. To reduce this activity to acceptable levels (from a health standpoint) will require either increased shielding, a reduction in beam energy, or other modifications.

The possible use of ^{15}O labelled ozone is under serious consideration for studies of toxicity at low concentration levels in laboratory animals. Preliminary measurements using a 2 MeV deuteron beam on a gaseous nitrogen target indicate substantial ^{15}O production via the $^{14}N(d,n)^{15}O$ reaction with only low levels of background neutron radiation. Further chemical studies are required before the potential of this labelled isotope can be completely determined.

The two-year NSF support of ^{11}C studies in plants concluded in August 1983. Until further funding is obtained, the 4 MeV laboratory will be used only for preliminary measurements in support of ^{15}O or ^{13}N production.

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** Biosystems Division, Texas A and M University
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H. DEVELOPMENT AND INSTRUMENTATION

1. 3 MeV Laboratory Development (C. R. Westerfeldt, R. O. Nelson, J. F. Shriner Jr.,* P. Ramakrishnan, B. Warthen, J. Vanhoy, W. Brooks, E. G. Bilpuch, G. E. Mitchell)

a. Machine Changes

As reported last year, we have installed a new HVEC stainless steel electrode accelerator tube in our KN Van de Graaff accelerator. During the past year we have successfully run an experiment (^{56}Fe(p,p'γ)) with this upgraded machine at energies up to 4.015 MeV. The new accelerator tube performed flawlessly--there was no indication of having reached a limit on the voltage gradient for this new tube. We have also performed an experiment (^{25}Mg(p,p)) from 800 keV to 2 MeV with this new accelerator tube. To improve the beam quality at energies below 1 MeV the high-energy half of the column was shorted to ground. This causes the voltage gradient on the low-energy portion of the column to double, approximating the more satisfactory accelerator tube optics at 1.6 to 2.0 MeV. The second half of the accelerator tube (high-energy end) thus becomes a drift section. For the ^{25}Mg(p,p) experiment the total energy resolution was 330 eV throughout the region studied, thus this new accelerator tube will not prevent us from obtaining good resolution--due to poor beam optics--at very low energies.

b. Electrostatic Analyzer Changes

The homemade optically coupled amplifier which was described in last year's progress report has been replaced with a commercial fiber-optic transmitter/receiver pair (MATH ASSOCIATES model 1200 XA/RA). This system has a bandwidth (-3db) of dc to 1 MHz. and very good dc stability. With this system one can apply correction signals (dc and ac) to the outer plate of the electrostatic analyzer which is biased between +4 and +20 kV above ground potential.

Recently the feedback system for the electrostatic analyzer was rebuilt to incorporate the new fiber-optic link and a new high voltage target rod driver. The new target rod driver incorporates negative feedback to stabilize the gain at 111, thus reducing gain drifts and the need for recalibration. This system has been tested but has not yet been used in an actual experiment.

c. Analyzing System Automation

The plans for interfacing the machine-energy analyzing system in the 3-MeV laboratory to a microprocessor control system have been delayed. The company from which this system was ordered (ANAC Ltd.) went into receivership in December 1982, barely one month before the scheduled delivery date of our system. After six months of extension we have decided to cancel the order: ANAC had difficulty completing the system, and there would be no practical warranty or effective technical support services available. We are now considering other systems (LSI-11 based) which are readily obtainable, but which will require much more development work on our part for hardware integration and software control programs.

It is hoped that we will have orders placed for a majority of the system components by late 1983 and have a simple control system installed and running by early 1984.

d. New Scattering Chamber

Construction of a new 17" scattering chamber has been completed and the chamber has been installed in the 3 MeV laboratory. After several initial problems with the vacuum system, a reasonable base vacuum of approximatly 2×10^{-6} Torr ($<5 \times 10^{-7}$ Torr with the liquid nitrogen cold trap filled) has been achieved. This chamber has provision for up to six charged particle detectors on the bottom table, as well as a fixed 90° monitor mounted on the chamber top. Since the bottom detector table can be rotated, we have the ability to measure much more-detailed angular distributions by rotating the lower six detectors to obtain a 13 point angular distribution. This is especially important when measuring the angular distribution of decay products from high-spin states ($\ell \geq 3$). This chamber is also electrically isolated from the laboratory ground allowing connection to a planned high-quality "clean" computer ground system which should further improve instrumental resolution by reducing noise levels in the electronics. The lower detector table also incorporates a system for cooling the charged-particle detectors with a closed-cycle refrigeration system. This should also help to improve the charged-particle detector resolution. The first experimental use of this chamber will be the final portion of the ^{56}Fe(p,p') experiment between 3.65 and 4.00 MeV.

e. A New Analog Signal Multiplexer

In an effort to improve the resolution of the charged-particle spectra, an Ortec model 475-8 Analog Multiplexer has been obtained. In the past, summing amplifiers were employed to sum the linear signals from several detectors onto a single line to be processed by a single ADC. The summing of the pulses and noise from up to eight detectors and amplifiers contributed substantially to the broadening of the detector spectra. The Analog Multiplexer replaces the summing amplifiers. This device multiplexes up to 8 linear detector signals onto an output line with 60 db separation between inputs. The use of this device has significantly improved the resolution of the charged particle spectra, making it much easier to resolve weak inelastic peaks, and peaks in spectra at foreward angles which were previously overlapping.

f. A New Automatic-Gain-Control Slit Current Preamplifier

We have developed a new preamplifier for use in generating an error signal from the control slits in our electrostatic analyzer system in the 3 MeV laboratory. This preamplifier incorporates two current-to-voltage converters, a difference amplifier, a summing amplifier, and and analog divider circuit. A block diagram of this amplifier is shown in Fig. H1-1. The beam currents intercepted by the two control slits are first converted to voltages, then both a sum and a difference of these two signals is taken. Finally the difference of the two signals is divided by the sum, yielding a difference signal which is insensitive to intensity fluctuations in the beam. This amplifier will operate over several decades of input current--more if very-high performance operational amplifiers are used. This circuit has been used in the 3-MeV laboratory and found to be superior to the commercial preamplifier which we had been using. We plan to build several more of these preamplifiers to replace the logarithmic preamplifiers now in use in the tandem laboratory for machine energy control. A paper detailing this amplifier and its applications is planned.

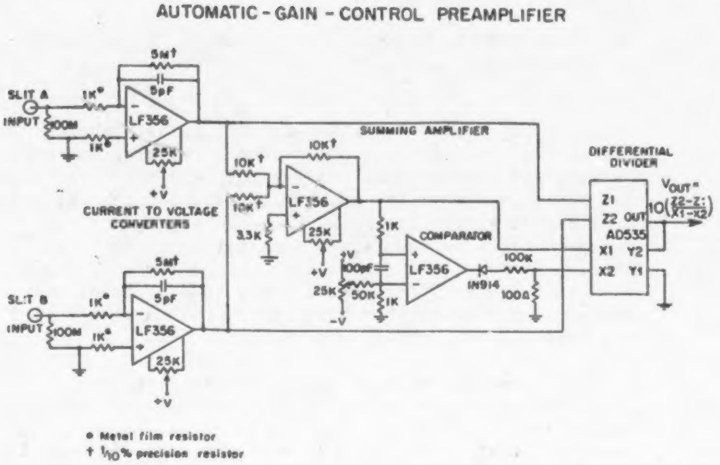

AUTOMATIC - GAIN - CONTROL PREAMPLIFIER
5M†
5pF
SLIT A
INPUT
1K*
100M
1K*
LF356
25K
+V
CURRENT TO VOLTAGE
CONVERTERS
SUMMING AMPLIFIER
10K†
10K†
10K†
LF356
3.3K
25K
+V
1K
COMPARATOR
+V
100pF
25K
50K
1K
-V
LF356
IN914
100K
100Ω
DIFFERENTIAL
DIVIDER
Z1
Z2
OUT
AD535
X1
Y2
X2
Y1
$V_{OUT} = 10\left(\frac{Z2-Z1}{X1-X2}\right)$
5M†
5pF
SLIT B
INPUT
1K*
100M
1K*
LF356
25K
+V
* Metal film resistor
† 1/10% precision resistor

Fig. H1-1. Automatic-Gain-Control Slit Current Preamplifier.

g. Terminal Amplifier

The terminal amplifier for the KN Van de Graaff accelerator has been redesigned to incorporate a commercial fiber-optic signal link in place of the homemade light-emitting-diode to photomultiplier tube signal link. The fiber-optic analog signal link (MATH ASSOCIATES model XA/RA 1800) has a bandwidth (-3db) of 10 Hz to 40 KHz, excellant linearity and very little noise. The homemade system had serious problems in that the high voltage power supply for the PMT had a substantial amount of 800 Hz ripple--which showed up in the output of the PMT and was subsequently used to modulate the beam energy. The fiber-optic link eliminates the PMT and the high voltage power supply. This new amplifier has been installed in the accelerator and tested in air. Actual beam tests are planned in the near future.

2. Tandem Accelerator Operation

a. Operation and Maintenance (R. L. Rummel, E. P. Carter, C. R. Westerfeldt)

For the period September 9, 1982 to September 1, 1983 the tandem accelerator was operated for over 6000 hours. Because the experimental demands for beam time remain high, the only times that the accelerator was not running during this period were during tank openings to replace the stripper foils or repair the terminal amplifier. One tank opening in March was required to change the charging belt when it began to disintegrate after 7644 hours of use. The replacement belt now has been in use for in excess of 3000 hours and is performing very well.

The tandem continues to run reliably up to 8.0 MV with short runs possible up to 8.5 MV. Operation above 8.0 MV is somewhat risky due to the condition of the accelerator tubes - two of which are original equipment and have in excess of 91,600 hours of useage.

b. Beam Profile Monitor (R. L. Rummel, C. R. Westerfeldt)

The lack of a good system for monitoring the beam position and size throughout the beam transport system in the tandem laboratory has long been a problem for experimenters. The lack of monitors in the low energy end, in the analyzing magnet systems, and in the experimental beam legs results in difficult and not-quantitative tuning of the beam. To alleviate these problems we have ordered a National Electrostatics Corporation (NEC) beam profile monitor for installation in place of one of the old HVEC scanners in the high-energy end of the accelerator. If this scanner proves to be a significant improvement over the old scanners we plan to purchase several more - up to a system limit of 12 - over the next few years. This system - when complete - should greatly simplify the transport of the beam from the ion sources through the low energy end, the accelerator, and the analyzing magnet systems.

In conjunction with the beam scanners, a project is underway to build a remote operated quartz viewer assembly. In this system a quartz viewer could be put into the beam (on an experimenters beam leg for example) from a control panel in the tandem control room. A small TV camera viewing the quartz will transmit the image of the beam spot to a monitor in the control room. The experimenters can then optimize steering and focusing of the beam at that point. If this project proves successful - as it has at several other laboratories - we plan to install this type of monitor on several of the experimental beam legs and possibly in the beam transport system as well.

c. Stripper Foil Development (J. Adams, J. R. Vanhoy, C. R. Westerfeldt)

In an effort to increase the lifetimes of our terminal stripper foils, we have been attempting to manufacture carbon foils in the range 5 to 10 $\mu g/cm^2$ by cracking ethylene gas in a dc electric field. Many laboratories report lifetime increases for these foils - especially for heavy ions - of factors of five or ten. We are presently testing these foils by subjecting them to several microamperes of proton beam - at several MeV - in the 3 MeV laboratory. When we have developed the techniques to routinely produce a higher quality foil we plan to install several of them in the tandem stripper for actual use. If the lifetimes of these foils prove to be significantly greater than those produced by an ordinary arc discharge, we will most likely begin using these foils on a routine basis in place of the ordinary foils.

These foils have other applications as well. If their lifetimes are indeed longer than the standard arc discharge foils, they would be useful as backings for thin targets as well. Whereas a typical high resolution experiment may require several targets due to breakage of the target backing while being irradiated by the beam, it may be possible to complete an experiment with only one target. This is especially important when using rare (and expensive) isotopes.

d. Problems with the 80°F Water System (E. P. Carter, R. L. Rummel, C. R. Westerfeldt)

We have recently experienced problems with the power supply for the 90° - 90° analyzing magnet system. It was discovered that the water cooling channels in the supply were partially or wholly blocked by sludge from the 80° F water system. This caused components to overheat and fail. Although the supply lines to the power supply were filtered, the filters were too coarse to catch the bulk of the material. We are now building some filter housings that will hold eight filter cartidges of a much smaller sieve size. We plan to install these assemblies on the 80°F water supply lines for all of the magnet power supplies as well as the magnets themselves. We hope that by running eight filters in parallel we can go several months between filter changes - even with the higher degree of filtration.

e. New Safety Panel (R. L. Rummel, E. P. Carter)

A new interlock and control system for the tandem beam stops has been designed, constructed and installed in the tandem control room. The large control panel has indicator lamps and switches for all beam stops superimposed on a layout of the entire beam transport system. In addition, radiation indicators show when unsafe conditions are present in any one of the eight monitored areas. If an unsafe condition exists in an area when the doors to that area are open, the low energy beam stop is put in - eliminating the hazard. To reset the interlock, the doors to the affected area must be closed and the interlock reset. All kill switches and door interlocks are shown for easy determination of interlock conditions. Provisions have also been included for computer control of any target room beam stop. The layout of the panel and the electronics lends itself to easy modification should the need arise.

f. Radiation Monitors (L. W. Seagondollar, E. P. Carter)

To help assure the reliability of the laboratory's radiation monitoring equipment, every radiation monitor and detector in the laboratory - both portable and fixed - was checked for proper function and recalibrated. The calibration was carried out in cooperation with the Duke University Radiation Safety Office. This will be done on a yearly basis, while function checks will be done on a monthly basis.

g. Compressed Air System Improvements (R. L. Rummel, E. P. Carter)

A new air compressor was purchased this past year when the old compressor started showing signs of imminent failure. After the new compressor was installed, the old compressor was shipped back to the factory for overhaul. When the rebuilt compressor returns, it will be reinstalled and used as a standby compressor for the laboratory's compressed air system. This should eliminate the possibility of a prolonged laboratory shutdown due to an air compressor failure.

h. Cyclotron Chiller Problems (R. L. Rummel, E. P. Carter, C. R. Westerfeldt)

The new cyclotron chiller which was installed last year has continued to give problems. The new interlocks and monitors which were installed in the cyclotron chilled water system last year have prevented any serious damage from occuring when the chiller has failed. The failures have all been relatively minor, but have forced the cyclotron vacuum system to be shut down for periods of days or weeks at a time. Since it takes a week or more to obtain a vacuum suitable for running the cyclotron after a vacuum system shutdown, it has been difficult to do very much development work on the new ion source and ramp circuit. Since it appears that the failures are due to specific - and usually minor - failures, we have hopes that the chiller will soon be running reliably and allow more routine operation of the cyclotron.

i. DENIS III Remote Controls (R. L. Rummel, E. P. Carter)

Work is well underway to complete installation of a set of remote controls for the new direct extraction negative ion source (DENIS III) located on the injector cyclotron. Full-energy tests of the cyclotron have been hindered by the inability to adjust the source controls while the cyclotron is running - due to the radiation levels present. Once these controls are completed, tests will resume on the ion source and ramping system with the aim of an experimental run utilizing the cyclotron before the end of the year.

3. Injector Cyclotron (R. L. Rummel, R. A. August, E. G. Bilpuch, E. P. Carter, T. B. Clegg, C. R. Howell, A. W. Lovette, N. R. Roberson, H. Robinson, C. R. Westerfeldt)

There are two primary goals of this project. First, to investigate the feasibility of operating a direct-extraction ion source in the stray magnetic field (B-field) in the area above the cyclotron magnet. This has included construction, installation, and testing of the source and associated beam optical elements. The major concern was the transport properties of low-energy beams (H^- and D^- ions) in this relatively strong B-field. Second, to develop a bunching system to pulse the ion beam into the few-nanosecond phase acceptance of the cyclotron in order to improve its efficiency (the percentage of injected ions that are successfully accelerated). The low efficiency of the cyclotron so far has precluded the use of low intensity ion sources such as polarized ion sources (PIS).

Prebunching (ramping) the injected beam at a fraction of the characteristic cyclotron frequency (25 MHz for protons and 13 MHz for deuterons) will also reduce the repetition rate of the extracted beam. The reduction in the repetition rate of the accelerated beam, from 25 MHz to about 4 MHz, will permit the use of time-of-flight (TOF) techniques. Since more than 50% of the experiments conducted at TUNL use TOF techniques, extending the availability of these techniques to the full Cyclo-Graaff energy range will greatly enhance TUNL's experimental program.

a. Beam Optics Improvements (R. L. Rummel, R. A. August, E. G. Bilpuch, E. P. Carter, T. B. Clegg, C. R. Westerfeldt)

In 1982, a direct-extraction negative-ion source was installed on top of the cyclotron so that the beam is injected directly into the vertical channel (throat) in the upper "yoke" of the magnet. The initial development and testing of ion source and optical elements were conducted with H^- beams. The results of the first series of tests revealed that the operation of the duoplasmatron was not signicantly affected by the B-field created by the cyclotron. However, there was much difficulty in transporting the beam from the source to the "dees". Because of beam pulsing considerations, the beam travels 3 meters at an energy of around 5 keV before being accelerated to the full injection energy of 17 keV. At this low beam energy small radial B-fields will cause irrecoverable deflections of the beam. Thus, much attention has been given to minimizing the the radial component of the stray

B-field and to using optical elements to compensate for its effects.

The source and its associated power supplies are supported by a 30.5 cm thick floor of reinforced concrete that is 139 cm above the "yoke" of the cyclotron. The steel reinforcements in the floor shield the source from both the static B-field and the rf power of the cyclotron. The source is secured to a metal stand that is anchored to the floor. Great care was taken to align it optically with the "throat" of the cyclotron. The injection channel (beam line from source to "yoke", excluding optical elements in "throat") is about 115 cm long. Optical elements were positioned for optimal beam transmission from source to cyclotron; neglecting the effects of the cyclotron's B-field. Initially, the portion of the injection channel below the floor was constructed of iron in order to shield the beam from the stray B-field above the cyclotron magnet. Since the area above the floor is well shielded from this field, aluminum pipe was used. In this configuration the transmission from source to "dees" was extremely poor; around 10%. Exploring different optical solutions made only minute improvements.

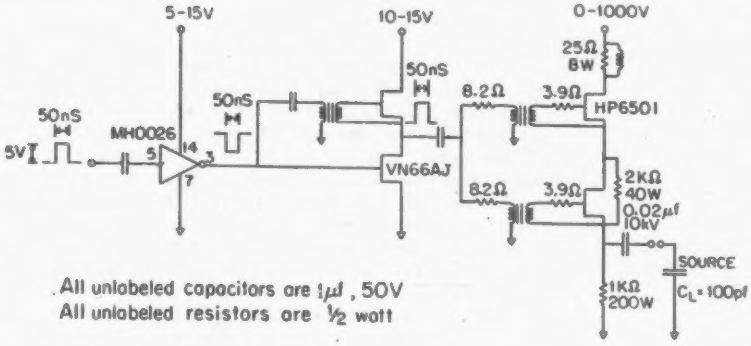
The transmission of the beam from source to the "dees" was significantly improved, mainly by two changes. First, a large portion of the iron in the injection channel was replaced with aluminum. Second, the mirror in the "throat" of the cyclotron was realigned. Mapping the B-field along the injection channel revealed that there were two strong magnetic lenses in the channel. One at the iron-aluminum junction just beneath the floor and the other at the iron-iron junction immediately above the "yoke". The first lens is caused by the high density of magnetic flux lines leaving the iron. The second lens is created by the change in magnetic flux lines due to the difference in thickness of the iron at the iron-iron junction. These lens effects were reduced by replacing all the iron above the "yoke" with aluminum. The reduction of these lenses resulted in a drastic improvement of the beam transmission. Because the lens effect of the B-field cannot be completely eliminated, additional steerers were installed to center the beam in the remaining lens.

Realignment of the electro-static mirror in the "throat" also made a substantial improvement in the transmission of beam to the "dees". The positions at which the beam entered and exited the mirror were determined by placing a piece of 1 mil mylar on top of the mirror's grid, striking it with beam, and then noting the positions of the beam spots. After the mirror had been properly positioned, essentially all the beam incident on the mirror was bent into the "dees". Typical operation of the system is around 40 μA of beam on the source cup (located immediately above the "yoke") and about 16 μA on the "dees". We are continuing to improve the overall transmission.

b. Beam Pulsing (C. R. Howell, T. B. Clegg, A. W. Lovette, N. R. Roberson, H. Robinson, C. R. Westerfeldt)

A linear voltage ramp (LVR) generator has been installed on the cyclotron injector source. Fig. H3-1 is a

LVR GENERATOR


5-15V
10-15V
0-1000V
25Ω
8W
50nS
50nS
50nS
8.2Ω
3.9Ω
HP6501
MH0026
5V
5
14
3
7
VN66AJ
8.2Ω
3.9Ω
2KΩ
40W
0.02μf
10kV
SOURCE
1KΩ
200W
C_L = 100pf

All unlabeled capacitors are 1μf, 50V
All unlabeled resistors are ½ watt

Fig. H3-1. Schematic of LVR generator. The LVR circuit rapidly charges up the 100 pf capacitance of the source through high-power FET's and discharges it through a high-power resistor. Generator is grounded to beam transport and is capacitively coupled to the source.

schematic of the LVR circuit. A 5 V, 50 ns wide square pulse drives the MH0026 clock driver, which in turn drives the gates of the two VN66AJ FET's. The output of the VN66AJ's drives the 1000 pf input capacitance of the HP6501 FET's via two pulse transformers. The pulse transformers serve the dual purpose of providing electrical isolation and of impedance matching. The HP6501's are high-power, high-speed FET's with a drain-to-source breakdown voltage of 450 V and are capable of sinking 6 A continuous drain current. The turn-on time of these FET's is typically 20 ns. In this application they are used as high speed switches in a RC circuit. The 100 pf capacitance of the source is rapidly charged up through the FET's and then slowly discharged to ground through a 1000 Ω carbon film resistor (this resistor consists of two 500 Ω, 100 W carbon film resistors in series that are oil cooled to increase their power dissipation capabilities). The value of the discharge resistor was chosen large enough so as to stay in the linear region of the RC discharge curve, while remaining small enough so that the voltage across the FET's would not exceed their maximum rating. This LVR generator is capable of producing peak-to-peak voltages of 600 V with rise times less than 40 ns.

There are mainly three effects of beam pulsing that determine the intensity of the beam that is captured by the cyclotron. First, the ramping voltage creates time dependent lenses, which distorts the static beam optics. Second, the ramping voltage might increase the intrinsic energy spread ΔE of the ions leaving the duoplasmatron. And third, the shape and amplitude of the ramping signal determines the width of the injected beam bursts. Measurements were conducted to separate the ΔE and ramping effects from the lens effects. The results of these tests indicate that the ramp creates a strong time-dependent lens between the anode and extractor. The effects of this lens could not be compensated for with static lenses, and thus a reduction in beam intensity resulted whenever the LVR was applied to the anode electrode. This lens effect was reduced by driving both the anode and extractor with the LVR. The remaining time-dependent lenses due to the ramp are small and can be compensated for with adjustments of static lenses.

A direct measure of the time structure in the injected beam could not be made because of its low energy and because of the bunching properties of the cyclotron. Instead, the profile of the accelerated beam was measured as a function of LVR settings (peak-to-peak amplitude and phase) and extracted beam intensity. The beam profile was measured by stopping the deuteron beam on a faraday cup before the tandem and detecting the γ-rays with a liquid scintillator. The anode signal from the scintillator was used to start a time-to-amplitude converter (TAC) and the stop was derived from the trigger signal to the LVR generator. Because the repetition rate of the ramping is one-third the cyclotron frequency, each time-of-flight (TOF) spectra contains three rf cycles (peaks) as shown in Fig. H3-2. The background

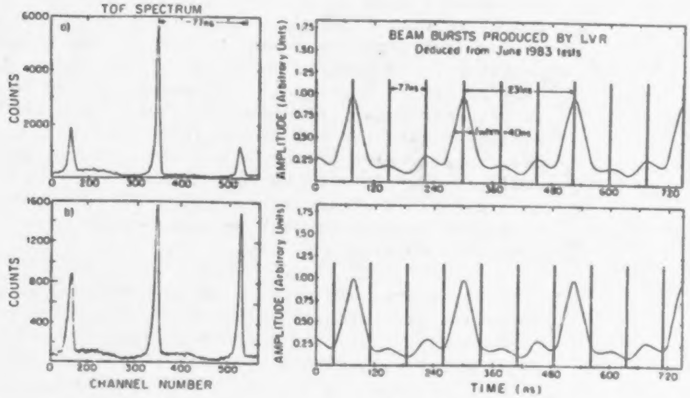


Fig. H3-2. Profile of beam that was extracted from cyclotron along with shape of injected beam as deduced from tests that were conducted in June 1983. These measurements were made by stopping the deuteron beam on a faraday cup and detecting the γ-rays with a liquid scintillator. The backgrounds under and between the peaks are neutrons from deuteron breakup. The characteristic frequency f_0 of the cylcotron is 12.95 MHz and the frequency of the LVR is $f_0/3$. The bold vertical lines show the relative position of the acceptance window of the cyclotron to the injected beam pulses.
(a) LVR phase adjusted for maximum beam intensity I_0.
(b) LVR phase adjusted for minimum beam intensity $I_0/2$.

under and between the peaks is caused by neutrons from deuteron breakup; no n-γ discrimination was used. The peak-to-peak voltage of the LVR was adjusted to maximize the amount of captured beam. For a beam transport energy of 6 keV, the optimum V_{p-p} = 480 V. Initially the ramp phase, relative to the main rf, was adjusted for maximum beam, and then subsequently adjusted to reduce the beam in equal decrements until a minimum intensity I_0 was reached; the phase change and beam intensity was recorded after each adjustment. The results of these measurements suggest that the injected beam pulses are nearly gaussian with a full width at half maximum (fwhm) of about 40 ns and are sitting on a DC background which is about 25% of the peak height.

According to calculations, the fwhm of the injected beam should be about 10 ns instead of the measured 40 ns. The additional time spread is believed to be a result of the enhanced ΔE of the duoplasmatron due to the ramping. There are two possible mechanisms in which the ramping can increase ΔE. First, AC (alternating current) ripple on the arc supply due to rf pickup of the ramp signal might increase ΔE because of instabilities in the arc current. Better rf chokes are needed to decouple the ramping voltage from the DC power supplies. And second, ripple between the anode and probe (intermediate electrode) could possibly increase ΔE. When the anode and extractor are driven with a 600 V_{p-p} ramping voltage, there is ~ 200 V ripple between the probe and anode. To eliminate this possibility, the probe must be driven along with the other electrodes.

Once the sources of time spread in beam pulsing has been determined and eliminated, we will then devote more attention to improving the LVR generator. A higher voltage LVR generator will permit larger injection energies and thus narrower beam bursts. One proposal is to use amplifier tubes instead of the FET's. Tubes will increase the voltage capability of the circuit and also improve the linearity of the LVR.

4. Polarized Ion Source

a. Operation and Improvements

The Lamb-shift polarized source has continued to be used heavily during the past year for experiments. A considerable amount of work has been done on the source to keep it in operating condition, especially since May when an epoxy joint on an einzel lens failed. This caused oil to leak into the vacuum system and caused a long sequence of difficulties and repairs during June and July. Also during July we installed new fiber optics links to the high voltage frame which have greatly improved the reliability of the source's micro-process based interlock system. Also, planning work has begun for installing the ANAC Wien filter and either moving the old source or acquiring a new source in order to accomplish the spin-axis orientations necessary. Details of these projects are given below.

b. Polarized Ion Source Microcomputer Enhancement (T. M. Mooney, X. Xanahian, T. B. Clegg)

The fiber optic link between the Polarized Ion Source high voltage frame and the controlling microcomputer has been re-designed and replaced. Noise problems with the old link, and the need for additional lines to service a newly installed digital voltmeter made wholesale replacement the attractive alternative.

Software is being developed to allow the VAX (thus, XSYS) to participate in the following proposed control sequence: experimenter selects the value of a beam parameter; the microcomputer sends appropriate signals to the Polarized Ion Source, attempting to set the parameter; the microcomputer reads voltages on the source and reports back that the state of the source is (in)consistent with the required beam.

An S-100 board has been designed, built, and tested which detects a system crash in the controlling microcomputer (e.g., due to a frame spark), and reboots the control program in this case.

c. Wien Filter Spin Processor Beam Optic Calculations

An initial design study for installation of a new polarized ion source and the ANAC model 2170 crossed-field spin processor has been based upon first order ion optical calculations. The processor, equipped with electrostatic quadrupole doublets at each end and power supplies capable of precessing the spin of a 50 keV D- beam through 90 degrees, was acquired in the summer of 1980. With recent emphasis on the study of the spin-spin interaction in nucleon-nucleus scattering and the initiation of a cryogenic polarized-target facility, efforts have been made to utilize this device. The present plan is to remove both the HE-source and DENIS I and inject the wien filter beam leg through the DENIS I port. A new atomic source, which would provide larger accelerated polarized beams, could then be installed at the head of this leg. Alternatively, the present LAMB-SHIFT source with a modified lens geometry could be used, however, the possibility of obtaining greater beam intensities is limited.

Physically, the wien filter consists of uniform electric and magnetic fields perpendicular to each other and to the direction of motion of the beam. The electric field exerts a constant force on all particles, whereas the magnetic field acts weakly on the slower ones and strongly on the faster ones. For the case of protons, the wien filter has very weak focal properties. In fact the wien filter is essentially a drift space for 90 degree spin precession of H- ions. However, the magnetic moment of the deuteron is much smaller than that of the proton and the larger fields required cause the wien filter to have stronger focal properties on these particles (i.e., it is not correct to treat the wien filter as a drift space in this case). The electrostatic quadrupole doublets are used to compensate for the focussing action of the precessor by requiring a beam waist at the center of the device. No precession error should result from ions taking different paths through the precessor since each ion should spend the required amount of time within the wien filter to obtain the proper precession angle.

Extensive effort has been made to find a suitable beam leg that would accommodate the wien filter apparatus. By using the beam transport program OPTIK 2 and by implementing the first-order ion-trajectory matrix describing the ANAC wien filter for H- and D- ions, confirmation of the feasibility of utilizing this device has been achieved. Progress is being made toward adapting the ANAC matrix into the optic code such that plots of the beam trajectory through the wien filter will be available.

The polarized ion source is followed by a gate valve and a Faraday cup. Then comes the electrostatic quadrupole doublet, the wien filter and the other electrostatic quadrupole doublet. The ion beam is then accelerated from 50 keV to 100 keV within a 5 inch electrostatic accelerator located immediately after the last doublet. A gate valve, Faraday cup and pumping station follow the acceleration tube and extends from the DENIS I port.

These calculations have been extended through the low-energy end of the accelerator. By considering einzel lenses two and three as thin lenses favorable results have been obtained at the center of the TANDEM. Using the formalism described in El Karah for an einzel lens with a thick central electrode and two apertures representing the outer electrodes, a direct relationship between focal lengths and the voltage applied on the lens can be obtained. The fields generated within an einzel lens are nontrivial. By restricting the beam to within 20 percent of the einzel's diameter effects due to aberations are minimal.

Further calculations are being pursued to see if the beam has met all requirements of the TANDEM acceptance over all possible energy ranges.

5. A Cryogenic Polarized Target Facility

The goal of the reseach project with the cryogenically polarized target facility is to measure differences in total cross sections for neutrons of opposite spin incident on polarized nuclei. An asymmetry in the cross section is related to spin-spin terms in the nucleon nucleus potential. Separate measurements with transverse polarized neutrons and longitudinally polarized neutrons can in principle separate central and tensor terms in the spin spin force.

The polarized target consists of a helium dilution refrigerator and a superconducting magnet. The first two years of the project were devoted to designing and assembling this system. All components of the complete facility were tested during the year and preliminary experiments were performed with longitudinally polarized 14 MeV neutrons incident on a polarized aluminum sample.

The cryostat components and dilution refrigerator are shown in Fig. H5-1. The dilution refrigerator is a model DR 430 from SHE corporation with a cooling power of about 2 μW at 10 mK. The magnet is a 7-Tesla split-coil superconducting magnet from American Magnetics, with a homogeneity of 0.1%

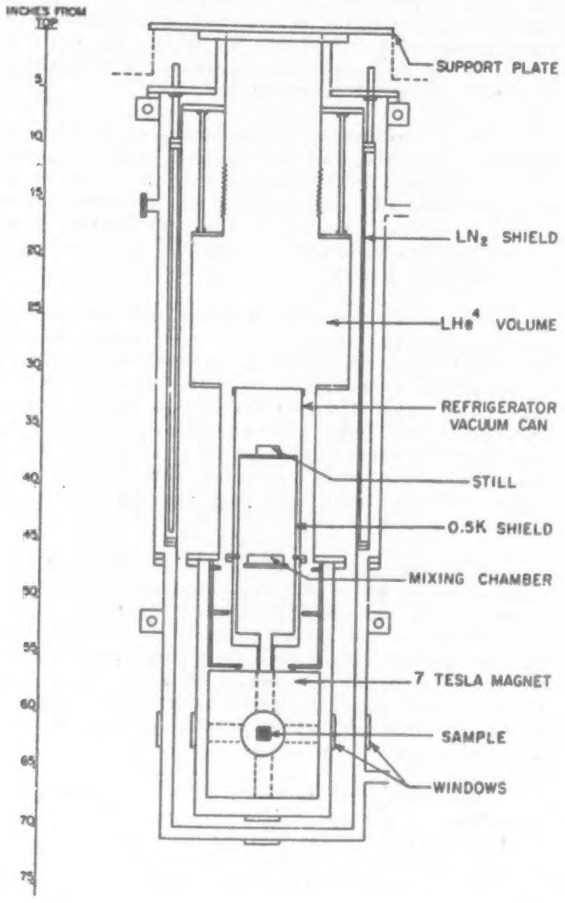

INCHES FROM TOP
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
SUPPORT PLATE
LN_2 SHIELD
LHe^4 VOLUME
REFRIGERATOR VACUUM CAN
STILL
0.5K SHIELD
MIXING CHAMBER
7 TESLA MAGNET
SAMPLE
WINDOWS

Fig. H5-1. Dewar, dilution refrigerator and other components of the polarized target.

over a 1-cm diameter spherical volume. The dewar hangs from a 10 ft. high tripod, and can be raised on air pads to minimize vibrations. The first cooldown of the dilution refrigerator was made in May with the magnet in place, but not energized. A dummy sample of solid copper was cooled to a temperature of 9.5 mK as measured via cobalt thermometry.

Carbon resistance thermometers were mounted on the mixing chamber, the still and the heat exchangers. They reproduced the values obtained by SHE during factory checkout prior to shipping and indicated the refrigerator was performing well up to specifications. At present the refrigerator requires about 100 liters of liquid helium for initial cool down. The helium boil off rate is 0.8 l/hr.

In the first test with polarized neutrons the cryostat magnet was energized to 85A, corresponding to a magnetic field of 69 KG. A 99.99% pure aluminum sample, 1.8cm(thick) x 1.8cm(wide) x 5cm(high) was cooled to 11.5 mK and held at this temperature for about 18 hrs. This corresponds to a nuclear polarization of 36%, and is a factor of four better than the best previously reported polarization for a bulk aluminum sample.[1] The closeness of this temperature to that obtained with the magnet off indicates that eddy current heating is not a serious problem.

A second test run in August was carried out with improved neutron beam optics but was less successful in terms of the cryogenics as the sample cooled only to about 18.5 mK. This corresponds to 23% polarization. The failure to cool down as well as before is not presently understood as the system was not opened between the two runs. We are checking the possibility that the silver solder joint between the copper rod and the mixing chamber results in erratic or poor thermal conduction to the rod and aluminum sample.

The primary thermometer used to monitor the temperature of the aluminum sample is a single crystal of cobalt, activated with 3 microcuries of ^{60}Co (Oxford Instruments Inc.). The crystal is mounted in a small hole 1" below the center of the sample and is soldered with Woods metal to maintain good thermal contact. The crystal axis is parallel to the external magnetic field.

The yields of the 1.33 and 1.17 MeV γ rays are obtained from spectra measured with an intrinsic germanium detector of efficiency 11.5% (Γ-X detector, Ortec Inc.). With the magnet off the detector can be placed up against the side of the dewar, 9" from the sample. The count rate is ~5 counts/sec in each peak. When the magnet is on, the stray field is about 5 KG at the edge of the dewar. It is not possible to operate the Ge detector in such a field without risking the possibility of avalanche break down inside the vacuum can of the detector. We have been operating the detector at 14" from the sample, using 2KG as a safe upper limit. The count rate is reduced a factor of two but we can obtain an anisotropy good to about 2% in one hour.

The neutrons were produced in the $D(\vec{d},\vec{n})$ reaction in a 3 cm long gas cell filled with 5 atm of deuterium. The deuteron polarization axis was at 11° with respect to the beam direction, in the horizontal plane. The deuteron polarization was typically 60%, giving neutron polarizations of P=46%.[2] The deuteron beam was pulsed at 4 MHz and neutron bunch widths were 4 ns.

The neutron beam passed through a 3/8" hole in a 2 ft long polyethylene collimator before hitting the polarized Al sample. The beam profile at 3.5 m from the gas cell is shown in Fig. H5-2. This measurement was made with a 1 1/2" diameter NE213 scintillator. The profile is consistent with geometric optics illumination of the collimator by the gas cell source. The beam size is smaller than the sample width and less than the

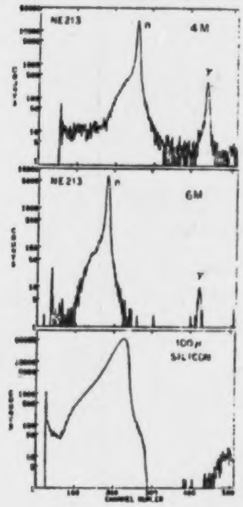


Fig. H5-2. Neutron beam profile measured 3.5m from the deuterium gas cell after collimation. The profile is approximately Gaussian with a FWHM of "2.5". The width expected on geometric considerations from a "3/8" collimator is "2.2".

diameter of the two neutron detectors used to measure the cross section asymmetry.

The neutrons were detected in two NE213 liquid scintillators back to back; the first was a 5"x2" scintillator, 3.81 m from the gas cell, the second was a 5"x5" scintillator 5.03 m from the gas cell. The detectors were operated at a high bias of 8 Cs. This reduced the count rate as compared to a more normal 1 or 2 Cs bias situation, but reduced backgrounds in the time of flight spectra considerably.

The zero degree neutron flux was monitored at the exit of the polyethylene collimator with a transmission mounted, 100 micron silicon surface barrier detector (Auc79). Time of flight spectra were stored for this detector so that incomplete beam burst detection could be taken into account. TOF spectra for the two neutron detectors and the monitor detector are shown in Fig. H5-3.

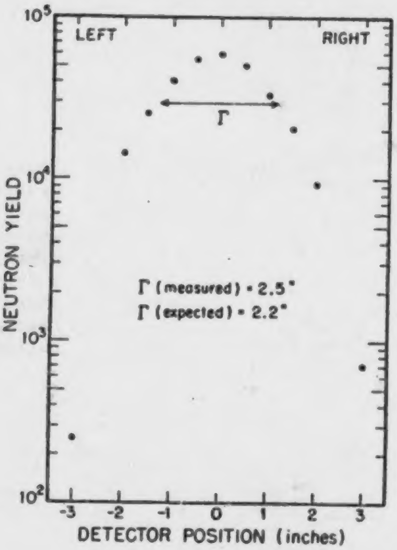


Fig. H5-3. Time-of-flight spectra obtained from the two zero degree NE213 liquid scintillators and from the zero degree silicon monitor detector.

Data were accumulated for about 15 minutes in each portion of an UP-DOWN-DOWN-UP sequence. (UP refers to neutron spin anti parallel to the beam, DOWN refers to neutron spin parallel to the beam. The target was polarized in a direction parallel to the beam.) The beam polarization was checked after each pair of the sequence.

In a single run typically 10^5 neutrons were counted by each of the NE213 detectors. About 10^6 counts were recorded by the monitor detector. A total of 25 UP-DOWN pairs of runs were made with the target cold (P=23%). A similar number were taken with the target warmed to 100 mK, the polarization then being zero.

The average asymmetries obtained from a preliminary analysis of the data from the second test run are listed in the table. Unfolding the monitor asymmetry leaves the net asymmetries shown at the bottom. The warm asymmetries are consistent with zero. The cold asymmetries are close to zero, and for the two detectors average to $(-2.5 \pm 4) \times 10^{-4}$. This represents a spin spin cross section of about 22 ± 35 mb, or less than 90 mb to two standard deviations.

With improvements in beam stabilization, we anticipate measuring asymmetries to about 0.01% accuracy in future experiments with niobium and aluminum. We are also installing a new dewar to allow us to orient the magnetic field vertically. In this orientation we will be able to use samples of double the present thickness, thus improving the accuracy with which the spin-spin cross section is determined.

Table H5-1

	Front detector	Back Detector	Monitor
Warm asym ± 3 x10-4	18 ± 12	19 ± 9	23
Cold asym x10-4	20 ± 6	19 ± 4	22 ± 3
Net warm asym x10-4	- 5 ± 12	- 4 ± 9	----
Net cold asym x10-4	- 2 ± 7	- 3 ± 5	----

Average asymmetry = (-2.5 ± 4)x10-4
Polarization of the beam P=0.46
Polarization of the sample f=0.23
Aluminum target areal density t=0.107 atoms/b

REFERENCES (Section H5)

1. P. P. J. Delheij, A. Girgin, K. Abrahams, H. Postma and W. J. Huiskamp, Nucl. Phys. A341 (1980) 21
2. G. C. Salzman *et al.*, Phys. Letts 45B (1973) 123
3. G. F. Auchampaugh, S. Plattard, N. W. Hill, Nucl. Sci. Eng. 69 (1979) 30

6. Proton Polarimeter Redesign (T. C. Spencer, C. Marzban, E. J. Ludwig)

The polarimeter which has been used to monitor the polarization of the proton beam from the TUNL Lamb-shift ion source has been redesigned to improve its performance. This polarimeter employs scintillation detectors to measure the left-right asymmetry of protons scattered from ^{4}He at 112 degrees over an incident energy range of 3 to 17 MeV. The protons entering the plastic scintillators are at energies considerably below the bombarding energy and hence background can be a severe problem. The improvements in the system include making smaller scintillators which must now be precisely aligned, moving the slits of the beam control system upstream of the monitor, and improving the alignment capabilities of the monitor. This new monitor is currently being built in the Duke machine shop.

7. Nuclear Target Preparation (R. L. Varner, D. J. Abbott, R. E. Anderson, J. E. Bowsher, R. E. Fauber, B. C. Karp, D. A. Janac)

Our group has prepared a number of targets in the past year for use in (p,p), (d,α), (d,t), (d,^{6}Li), and (α,α) experiments. Table H7-1 lists the targets and the means used to prepare them.

We have, in the past year, mastered several new techniques and materials for use in target prepartion. Among these are:

1) a technique for reduction of metal oxides in low pressure hydrogen gas in the bell jar to be used for evaporation. This permits higher temperature reductions to be made easily and quickly.

2) We have learned to prepare targets on polished metal[1] or glass slides, by scraping the prepared target off with a razor blade. For relatively soft and thick targets, e.g., the Ca and Sn in the table, this technique can produce superior targets.[2]

3) We have started using polished metal plates[1] for substrates, replacing glass sides as substrates for salt release agents. These substrates give better results for some materials, especially the ferrous metals (Fe and Ni).

REFERENCES (Section H7)

1. FerroPlate is the material we use (available from photographic supply stores).
2. A. H. Bennink and T. W. Tuintjer, KVI Annual Report, 1980 (KVI, Gronningen, Netherlands)

Target Preparation Table

Target	Form	Technique	Boat	Thickness	Backing(Thick)	Release Agent	Notes
				$\mu gm/cm^2$	$\mu gm/cm^2$		
^{24}Mg	MgO	Vacuum evap.	Ta	2-20	^{nat}C(5-10)	----	Reduction-Distillation[1] with Zr powder.
^{40}Ca	Ca*	Vacuum evap.	W	150-300	self-supp.	none	Scraping technique (Bennink)
^{48}Ti	Ti(foil)	Rolling	---	~300	self-supp.	----	
$^{54,56}Fe$	Fe_2O_3	Vacuum evap.	Al_2O_3 cm Mo dimple	150-250	self-supp.	NaCl	Oxide reduced by H_2 in evap.
^{60}Ni	Ni	Vacuum evap.	"	150-300	self-supp.	NaCl	Slow evap was best
^{89}Y	Y*	"	"	300	"	NaCl	Foils fragile. Low survival rate
$^{116,120,124}Sn$	SnO_2	"	Mo dimple	300	"	NaCl or none	Best targets were scraped. Reduced in H_2
$^{134,136,138}Ba$	$BaCO_3$ $BaNO_3$	"	Ta crucible	150	^{nat}C(20)	----	Reduction-Distillation of HaO, $HaCO_3$ and $HaNO_3$ reduced to BaO
^{209}Bi	Bi*	"	W dimple	400	self	NaCl	

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[1] J.M. Heagney and J.S. Heagney, Fifth Annual Conference of INTDS, Los Alamos, NM., 1976 pg. 92.

[2] J. Gursky, Los Alamos National Laboratory, private communication.

[3] The reduction of $BaCO_3$ to HaO was accomplished by heating in vacuum. The $BaNO_3$ was reduced to $BaCO_3$ by dissolving in distilled water and precipitating $BaCO_3$ with generous amounts of $(NH_4)_2CO3$.

* Natural abundance materials were used.

TABLE H7-1. Target Preparation Summary.

8. **High Energy Chopper** (H. G. Pfutzner, C. R. Howell, T. B. Clegg, S. E. Edwards, J. P. Edwards, A. W. Lovette, Ma Shan-xian)

A major part of the long term effort to improve the time width of the beam pulses used for time-of-flight (TOF) measurements, has been the installation, testing, and modification of the high-energy (post-acceleration) chopper.

The chopper is an L-C resonant system tuned to 20 MHz. Beam bursts pass between two 1"x2" vertical deflection plates. These plates are the primary capacitive elements of the circuit and two large 6-turn coils provide the inductance. The plates are driven in push-pull mode by a large amplifier, elements of which are contained in cans directly attached to the resonant chambers, as shown in Fig. H8-1.

By chopping at 20 MHz instead of the 4 MHz beam pulse repetition rate, one has a sharper slope in the linear region of the sine wave and can thus more effectively chop away the "tails" of the beam bursts. The 20 MHz chopper drive signal must be phase-locked to the 4 MHz beam pulses. Fig. H8-2 is provided to indicate how the phase-locking, frequency multiplication, and phase delay are accomplished.

In December of 1982 the chopper was installed after the analyzing magnet on the unused 59° beam leg. Several tests in December and January pointed out the need for a good vacuum in the chopper, and a capacitive beam pickoff ahead of the chopper to provide a trigger free of phase jitter. Water cooling for the inductance coils was added to eliminate a drift in the high voltage amplitude which was caused by temperature drifts in the coils. A test in February using a polarized deuteron beam with the above modifications included showed that a beam pulse with FWHM < 1 ns was attainable. Standard TOF techniques were employed to measure the pulse width. A second capacitive pickoff was placed in front of a gold foil target which provided recoil electrons to go into a charged particle detector (CPD).

In May the chopper was permanently installed after the tandem just ahead of the first analyzing magnet (20-70). A permanent capacitive pickoff was installed just after the tandem's high energy base plate. This configuration (shown schematically in Fig. H8-2) allows for chopping in any beam leg. A test was performed using DENIS II beam and the neutron-TOF facility along with the CPD mentioned above. A pulse width of

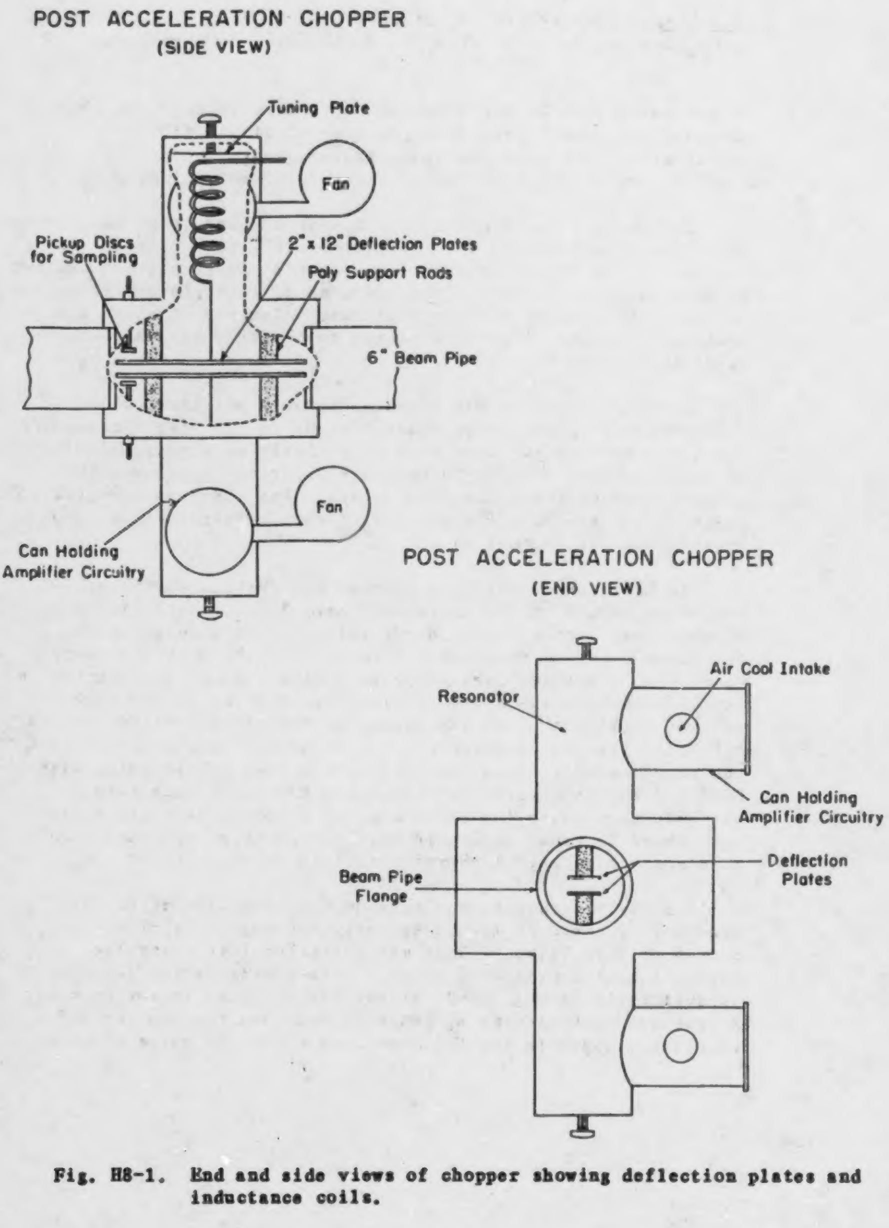
POST ACCELERATION CHOPPER
(SIDE VIEW)
Tuning Plate
Fan
Pickup Discs for Sampling
2" x 12" Deflection Plates
Poly Support Rods
6" Beam Pipe
Fan
Can Holding Amplifier Circuitry
POST ACCELERATION CHOPPER
(END VIEW)
Resonator
Air Cool Intake
Can Holding Amplifier Circuitry
Beam Pipe Flange
Deflection Plates

Fig. H8-1. End and side views of chopper showing deflection plates and inductance coils.

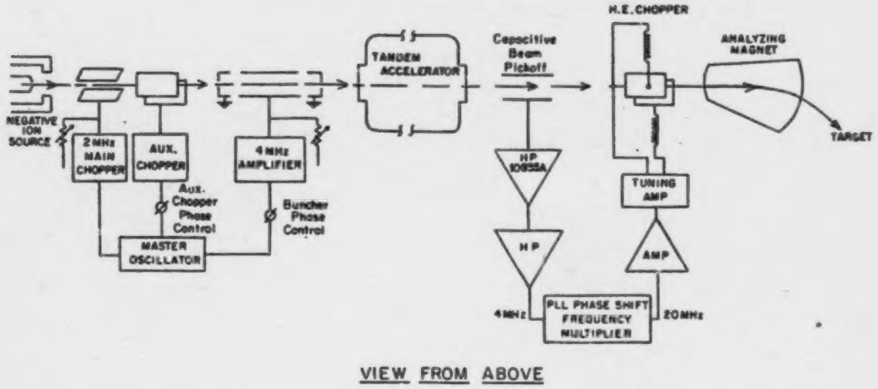
NEGATIVE ION SOURCE
2 MHz MAIN CHOPPER
AUX. CHOPPER
Aux. Chopper Phase Control
4 MHz AMPLIFIER
Buncher Phase Control
MASTER OSCILLATOR
TANDEM ACCELERATOR
Capacitive Beam Pickoff
HP 10855A
HP
4 MHz
PLL PHASE SHIFT FREQUENCY MULTIPLIER
20 MHz
H.E. CHOPPER
TUNING AMP
AMP
ANALYZING MAGNET
TARGET
VIEW FROM ABOVE

Fig. H8-2. Schematic drawing of all the beam pulsing elements used in the DENIS II configuration.

1 ns was achieved again but was not reproducible due to coupling with the beam-leg optical elements. The vertical slits used to stop the deflected beam were located after two quadrupole lenses which seemed to be capable of focussing deflected beam back in with the undeflected beam.

In August an additional set of vertical slits was installed in the 59° leg just after the analyzing magnet and before the quadrupole lenses. The effect of this change was obscured by a newly arisen problem in the phase-locked-loop circuit. The 20 MHz drive signal jitters with respect to the 4 MHz pickoff signal. At the time of this writing a possible solution for this problem is ready to be tested. The system still shows promise for getting 1 ns pulse widths with the CPD.

I. COMPUTER RELATED DEVELOPMENTS

1. TUNL Computer Facilities (C. R. Gould, M. Boyd, N. R. Roberson, S. E. Edwards)

The TUNL data acquisition and analysis system XSYS has been operational on a VAX 11/780 since mid 1980. The features of this system were described at the Oak Ridge computer conference two years ago[1-4] and more are recently at the Berkeley conference in May.[9]

Our VAX configuration is shown in Fig. I1-1 and has remained relatively stable since delivery of the original system. Memory

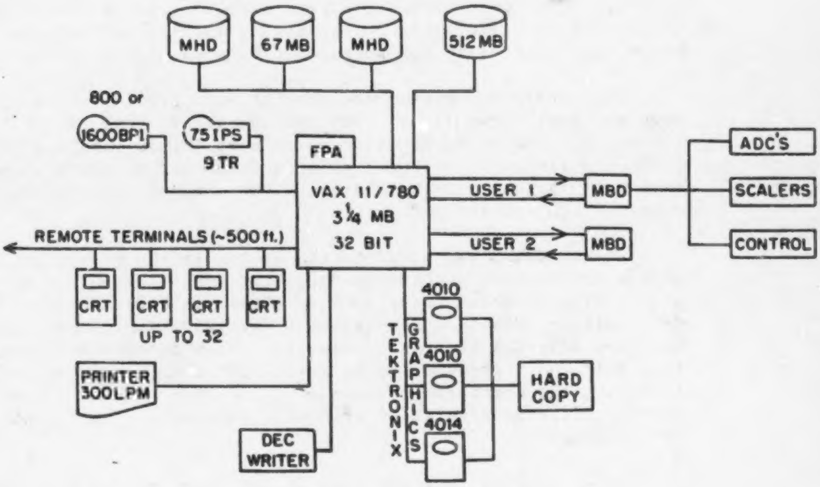
MHD
67 MB
MHD
512 MB
800 or
1600BPI
75 IPS
9 TR
FPA
VAX 11/780
3¼ MB
32 BIT
USER 1
USER 2
MBD
MBD
ADC'S
SCALERS
CONTROL
REMOTE TERMINALS (~500 ft.)
CRT
CRT
CRT
CRT
UP TO 32
PRINTER
300LPM
DEC
WRITER
TEKTRONIX
GRAPHICS
4010
4010
4014
HARD
COPY

Fig. I1-1. Configuration of the TUNL Vax Computer System.

has been expanded to 3.25 MB and a CDC 512 MB disc drive has been added directly to the SBI using an EMULEX controller. The total number of users is still about 80, but the increased memory now allows us to support 30-35 processes and subprocesses without significant degradation of response time. Typically ten of these processes will be associated with the primary data acquisition user, utilizing up to 20% of the available CPU time. The total number of terminals is twenty and remote dial in is supported on three outside lines.

The TUNL experimental program concentrates on light ion and neutron physics with major emphasis on polarized beam experiments. Most measurements require relatively simple hardware configurations involving single parameter and multi parameter (less than five) data acquisition with total event rates not in excess of 50K ADC words per second. The software as written can support up to 30 parameter events (and could easily be expanded further) but this capability has not been exploited in any experiments so far. The interface hardware is handled in a single CAMAC crate connected to a microprogrammed branch driver (MBD) (Ref.5). The software can handle multi crate systems, but again this capability has not so far been required.

The single MBD system and the VAX have proved very reliable over the last three years. The MBD appears to have been responsible for at most two or three unexplained bugchecks or lockups during this period. CAMAC modules can be moved around freely if the crate is off-line and the subprocesses associated with the MBD are stopped.

A second MBD was added to the system in the past year. This allows for testing of CAMAC modules and for check out of data acquisition programs prior to beam time. We encountered difficulties in making the system of two MBDs operational, and it only recently has been made reliable. Simultaneous interrupts from both MBD's appeared to be associated with a hardware problem involving a power fail sequence on the UNIBUS. This sequence aborted all processes associated with outstanding interrupts on the UNIBUS.

In discussing this problem, it was noted by Jim Anderson (University of Manitoba) that the MBD circuits which provide the Unibus control signals are improperly designed. As delivered, the MBD operates properly only if it is the last device on the Unibus. With two MBDs connected to the Unibus, this design problem causes failures with both NPR (non-processor-request) data transfers and interrupts. After making a few simple circuit changes to correct this problem, tests carried out with count rates up to 30K/sec. over several days revealed no failures. The dual MBD system has now been made available to the staff for further testing in routine use.

XSYS is written mostly in Fortran and runs under VMS. The limitations on array sizes, numbers of parameters etc. are associated with a few dimensioned arrays which are easily changed. We have used the VAX implementation of the event analysis language EVAL for all data sorting.[4,6] The ability to call a Fortran subroutine has been added, providing enhanced capability for complicated data manipulation. The EVAL compiler is easily modified and features of interest to special groups of users can be accomodated without great difficulty. We have not needed to extend the options beyond those discussed in Ref. 3. Versions of VAX EVAL are in use at 11/750 installations at McMaster University[7] and the University of Manitoba.[8]

A 200 page user's manual on XSYS was developed a year ago. The bulk of this information is accessible on line to our users via VMS HELP facility. The modular nature of the system has made it quite easy to keep this information up to date and the repertoire of commands has grown considerably since the system was first brought on line. Many people continue to be involved in specific aspects of XSYS, but the bulk of the support now rests with one part time person.

XSYS FEATURES

The TUNL version of XSYS now includes the following features:

1. Acquisition of single and multi parameter data from CAMAC using one of two separate MBD-11's. Total data area size per user is 1/2 MByte. Total number of one or two dimensional spectra is 256.

2. Manipulation and storage of events using the event analysis language EVAL and FORTRAN routines.

3. Execution of XSYS commands from the DCL command line or from COM files.

4. Linear and logarithmic display of one dimensional spectra on Tektronix storage scopes. Provision for setting gates for sorting, fitting backgrounds, and extracting peak yields.

5. Display of two dimensional spectra via density contour plots, with provision for setting multiple 2-D gates having arbitrary shape. 64x64 arrays can be displayed with up to five scales of intensity. Larger arrays (up to 256x256) are displayed with single points. Non square arrays are allowed but the sizes have to be powers of two.

6. Storage and recall of spectra from tape and disk.
7. Event by event storage of data into tape or disc files for offline sorting.
8. Addition, subtraction and normalization of spectra with propagation of associated errors.
9. CAMAC scaler read in, with window sum, preset, or timer options to turn off data acquisition.
10. Refresh display of scalers, dead time corrections and user calculated information on VT-100 terminals.
11. Automatic execution of user defined XSYS and DCL command files from FORTRAN images.
12. Unified XSYS error handling via VMS system services.
13. Online XSYS documentation via the VMS "HELP" utility.

Documentation includes the following files, prepared with DSR (DEC standard runoff):

1. INTRO.MEM
Overview of XSYS and discussion of how to put together a data acquisition or a data analysis program. An installation guide for XSYS is also included.

2. COMMANDS.MEM
Documentation on the XSYS commands presently available. Abbreviated versions of this file are available on line via the HELP facility.

3. EVAL.MEM
The EVAL programming manual. Data sorting is handled with EVAL code and an EVAL program is needed for processing ADC data or buffer tape data. For complicated data manipulation, a FORTRAN routine can be called from within the EVAL code.

4. SUBR.MEM
XSYS subroutine documentation. This is of interest if somebody is writing an XSYS command that is not in the present system.

5. DAP.MEM
DAP file documentation. Each EVAL program needs an associated DAP file to set up buffers and to communicate with the CAMAC hardware. The scaler read in subprocess also

requires a DAP file.

6. DSDOC.MEM
   Documentation on the internal data structures in XSYS.

The hardware manual for the TUNL interface and ADC's.

Data Acquisition Interface

The data acquisition interface currently in use follows closely the design considerations presented at the Oak Ridge Conference[3] and only salient features will be given here. The system employs an MBD which connects the VAX Unibus to a CAMAC Branch Highway. A schematic of the MBD-CAMAC interface is shown in Fig. I1-2. It is seen that the design has remote inputs for

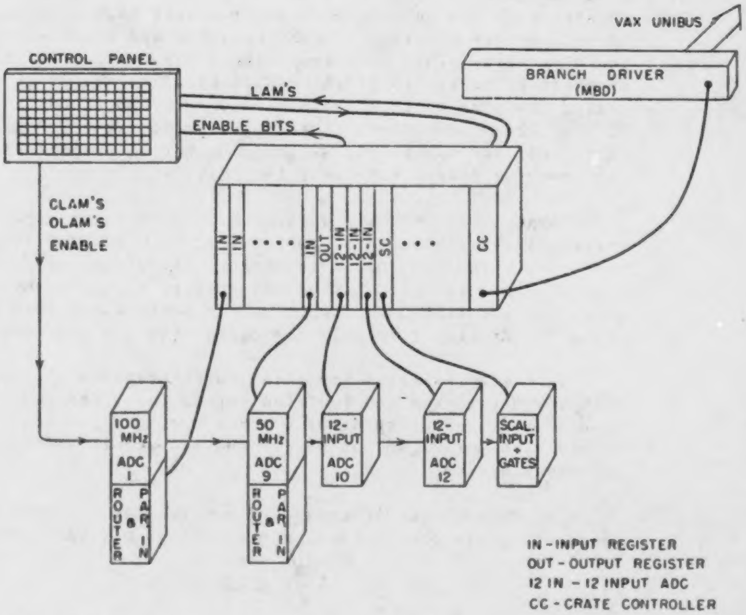
VAX UNIBUS
BRANCH DRIVER (MBD)
CONTROL PANEL
LAM'S
ENABLE BITS
CLAM'S
OLAM'S
ENABLE
IN
IN
....
IN
OUT
12-IN
12-IN
12-IN
SC
...
CC
100 MHz ADC 1
ROUTER & PAR IN
50 MHz ADC 9
ROUTER & PAR IN
12-INPUT ADC 10
12-INPUT ADC 12
SCAL. INPUT + GATES
IN - INPUT REGISTER
OUT - OUTPUT REGISTER
12 IN - 12 INPUT ADC
CC - CRATE CONTROLLER

Fig. I1-2. A schematic of the MBD-CAMAC Interface for the TUNL Vax Computer System.

all the CAMAC modules in the system. This has increased the reliability since users (often inexperienced) do not "handle" the CAMAC module directly.

There are 6 standard ADC's (four 50 MHz and two 100 MHz) connected to CAMAC parallel input registers. Flexibility is provided by the control panel which allows, via simple push buttons, any arrangement of these 6 ADC's into single or multiparameter groups. Reset signals are sent to the ADC's associated with multiparameter grouping after all the CAMAC registers are loaded. This allows the ADC's to process the next event concurrently with the transfer, by the MBD, of the contents of the registers to the VAX memory. Overall dead-time is reduced in this way. For those experiments requiring many parameters but with low count rate, three LRS 12-input ADC's with fixed 108 μsec conversion time are provided.

The MBD operates with a single re-entrant general purpose data acquisition program (GDAP) for all eight channels. The MBD, running with the current program, requires 13.2 μsec to respond to a LAM, read one 16-bit CAMAC register and transfer the results to VAX memory. This corresponds to a data rate of 75 KHz for a repetitious pulse. A slight modification to the program will reduce the time to 10.9 μsec which corresponds to data rates of 90 KHz. Each additional CAMAC register requires 6.2 μsec. Therefore, for events with a large number of parameters, the MBD can transfer data a rate near 160 KHz.

CAMAC scaler modules with 24 bit scalers are used in the system. The experimenters are provided with 18 24-bit scalers with remote inputs. Of these 12 have individual gates for each scaler. There are also two preset scalers which can be used to stop data acquisition. Normally, the scalers are read every 1-2 sec and a display terminal is updated with the new results.

Optically isolated input and output registers, a slow ADC with 16 multiplexed and isolated inputs (used for sampling dc levels) and a stepping motor control are used primarily to control the polarized ion source and the accelerator beam transport system.

The MBD, the CAMAC crate and modules have operated for three years with only one failure; a scaler chip had to be replaced.

XSYS OVERVIEW

XSYS consists of stand alone Fortran modules which communicate with each other via permanently resident global sections of memory. The global sections contain all the data arrays, buffers and control information associated with a particular user. Data are stored in the global section XDATA (XDATA.DAT on disk), and control information is in the section XSCOM (XSCOM.DAT on disk). These sections are group global sections, so they are distinct, and independent, for users with different group UIC numbers.

XDATA is 1024 pages long. Each spectrum is stored in an array in XDATA. Each element of that array corresponds to one channel of the spectrum. XSCOM is 60 pages long.

Up to 256 different 1D or 2D spectra with 2 or 4 bytes per channel can be allocated. 1D spectra can be of any length, however, the maximum number of channels that can be displayed at one time is 4096. 2D spectra can be up to 256x256, also with 2 or 4 bytes per channel. 2D arrays can be nonsquare but the sizes must be powers of two. 64x64 is the most useful upper limit size; displays of larger size arrays use a single level of intensity and are generally quite slow.

To write a data acquisition program, three types of file are needed. They are COM, DAP and EVL files. An analysis program does not use DAP files. It will use EVL files if buffer tape sorting is involved. Otherwise it will consist only of COM files. The file types are:

1. COM files. These files are written in DCL and contain the XSYS commands to be executed at various stages of the experiment, for example, at start up time, when a run ends, etc. Users are mostly not concerned with the details in XSYS and are interested only in what COM files they have to use. Most of the present effort in our laboratory is centered around tailoring COM files for very specific applications.

2. EVL files. These contain the sorting algorithms for handling the ADC data in the event buffer. Each active MBD channel requires its own EVAL sort program. These files are developed in conjunction with the DAP files since the DAP file determines the order in which ADC's are read and transferred into the event buffer.

3. DAP files. These are CAMAC and subprocess control files. They contain the CNAF commands for the actual CAMAC crate configuration, and information on the buffer sizes used by the MBD. Each active MBD channel requires such a file. DAP files are also used for general subprocess control information such as the scaler-timer preset or the scaler display. These files are the only place where reference to a specific hardware set up is made.

Computer Related Developments

During an experiment the data flow from ADC's through CAMAC into the MBD, and from the MBD into buffers in the VAX via DMA transfer using the direct data path of the UNIBUS. The MBD interrupts the VAX when the buffer, typically 2048 16 bit words, is filled. This interrupt completes a QIO, and the subprocess is activated to sort the data. The data are double buffered in the VAX, so the MBD is filling another buffer while the VAX is sorting the first. There are two buffers and a sort subprocess for each active MBD channel. The sorting algorithm for each subprocess is determined by the EVAL code written by the user. The EVAL code sorts the events and increments spectra previously defined by the user. In general this code will be different for each of the six possible MBD channels. The MBD has eight DMA paths (0-7) but we use channel 6 for scaler control and channel 7 for VAX-MBD communication. The data flow during analysis of an event tape is the same, except that the VAX buffers are filled from tape or disk instead of from ADC's.

XSYS and EVAL can handle one and two dimensional spectra. Each 1-D spectrum has its own set of gates. A gate is defined by two numbers, the upper and lower channel limits of the gate. In 2-D spectra, each gate is shared by spectra of the same size and gates are defined by bit maps stored in data areas. Gates can be of arbitrary shape.

Scalers are handled by a special subprocess and are read when the subprocess is awakened by the system timer, or when the user requests an update. A preset scaler option can be used to turn off data taking. The scaler values are displayed on a dedicated VT100 terminal connected to a remote TV display. This scaler display subprocess includes options for screen formatting, automatic update of scaler values, calculating quantities of interest, and outputting messages.

The user displays his spectra on the Tektronix terminals using Fortran programs DISP and TDD. DISP has provisions for fitting backgrounds, computing areas, setting gates and setting scales for 1-D spectra. TDD contains similar functions for operating on 2-D spectra. Unlike normal XSYS programs, the display routines stay resident and have the graphics terminals permanently allocated to themselves. Gates for EVAL can be set from these programs.

Error reporting in XSYS is handled through the VMS MESSAGE utility. Error and information messages are defined in the message file [XSYS.ERR]XERR.MSG. These messages are accessed and output through system services called by the XSYS subroutines XERROR for processes and XSPERR for sub-processes.

The file XERR.MSG follows the format described in the VMS

MESSAGE utility manual. The messages defined utilize the FAO (formatted ASCII output) facility to output the current time and one optional numeric parameter when the message is invoked. There are four groups of error messages, differentiated by their facility numbers (the . FACILITY directive in XERR.MSG). The first group is used to report errors from system service calls. The numeric argument in these messages is assumed to be the return value (error number) from the system call. The second group contains the remainder of the XSYS error messages. The third group contains informational messages which XERROR will report without causing the image to exit. The fourth group of messages are used by the EVAL compiler.

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2. Computer Facility for the 3-MeV Laboratory

The PRIME computer is scheduled to be replaced this fall. It is now over nine years old and is no longer able to meet the needs of the experimenters for larger and more sophisticated programs (its maximum program size is ~ 100 KB). In addition both the computer and its disk and tape subsystems are having more frequent failures and would eventually require major repair or replacement costs.

Although we originally intended to replace the PRIME with a Digital Equipment Corporation (DEC) VAX 11/730 computer, we have decided instead to purchase a VAX 11/750 computer from a systems house. We were able to configure a system based on the 11/750 for approximatly the same price as the DEC quotation on a 11/730 system. This new computer will be fitted with a 160 MB Winchester disk drive and a dual density streaming tape drive. Main memory will initially be 1 MB, but can be expanded to 2 MB if the need arises. It will have ports for up to eight terminals, three of which will be dedicated to data acquisition or off-line analysis. The data acquisition interface and software will be the same as is used on the laboratory's VAX 11/780, thus standardizing both the hardware and software systems throughout the laboratory. Although the system initially will not have the floating point accelerator, this should be added at a later date.

3. Dot-Matrix Plotting System (M. W. Clark, D. A. Levine, R. L. Varner)

We have written and installed the required device dependent routines for GRZ[1] to perform high resolution dot-matrix plots on a Printronix printer. The Printronix is the main printer attached to the VAX 11/780 at TUNL. The installation of dot-matrix printing was made possible by the upgrade of the VMS operating system to version 3.0.

This plotting package is relatively transparent to the user, allowing plots designed for the Tektronix 4010 display scope to be run on the printer with very few required changes. Furthermore, the new package utilizes some GRZ high level features not available on the 4010, namely character rotation and size changes.

We are currently engaged in converting the dot-matrix package to an IDS 460 Paper Tiger printer. This conversion is not straightforward, since the 460 utilizes a different scheme for arranging the bits it recieves. The two printers, though, represent the two basic schools of design in dot-matrix, and it should be easy to adapt one of these packages to any dot-matrix printer.

We are also hoping to install a dot-matrix programming package in SPEAKEASY,[2] which has been recently installed on the VAX.

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4. Optics (D. Levine, R. Varner, W. J. Thompson)

We have modified the version of OPTICS,[1] the interactive optical model code, installed on the VAX.[2] OPTICS performs single-shot calculations of differential cross-sections, vector and tensor analyzing powers, calculates the reaction cross-section, and includes an optional compound-elastic calculation. OPTICS calculates these quantities very quickly on the VAX, typically in less than one second.

The Vax version of OPTICS preserves all of the capabilties of the old version and includes several new features: I/O option control is menu oriented; optical model parameters and calculation accuracy control parameters can be referenced by name at the terminal; plots are produced at the terminal using GRZ graphics; all input is from data files or the terminal and tabular output is to a file.

The features included within the last year are:

1) A dump file, which a user can create before leaving the program and read into the program the next time he runs it in order to continue the last session.
2) An optional terse mode which causes supression of the explanatory portions of the menus.
3) An automatic or master sequence option by which the user can progress through the menus following a pre-stored list of commands instead of typing the commands each time.

A complete instruction manual for the VAX version of OPTICS has now been written.

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APPENDIX I

A. PUBLISHED JOURNAL ARTICLES

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21. Production of High-Energy-Resolution α Beams for Resonance Studies, R. E. Fauber, E. J. Ludwig, T. B. Clegg and B. C. Karp, Bull. Am. Phys. Soc. (November 1983 meeting)

22. Polarized Ion Source Optical Communication and Microcomputer Interfacing, T. M. Mooney, T. B. Clegg and S. Ma, Bull. Am. Phys. Soc. (November 1983 meeting)

23. The (d,^{6}Li) Reaction Induced by Tensor-Polarized Deuterons, J. E. Bowsher, T. B. Clegg, B. C. Karp, E. J. Ludwig and R. L. Varner, Bull. Am. Phys. Soc. (November 1983 meeting)

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25. Global Optical Model Analysis of Polarized Proton Scattering at Low Energies, R. L. Varner, R. E. Anderson, B. L. Burks, T. B. Clegg, E. J. Ludwig, W. J. Thompson and J. F. Wilkerson, Bull. Am. Phys. Soc. 28 (1983) 970

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27. Spin-Spin Interactions in Nucleon-Nucleus Scattering, Thomas L. McAbee and W. J. Thompson, Bull. Am. Phys. Soc. 28 (1983) 970

28. Vector and Tensor Analyzing Powers of the ^{28}Si(d,α)^{26}Al Reaction at 16 MeV, B. C. Karp, E. J. Ludwig, R. E. Anderson, T. B. Clegg and R. L. Varner, Bull. Am. Phys. Soc. 28 (1983) 651

29. The ^{13}C($\vec{n}$,γ_0)^{14}C Reaction, M. C. Wright, H. Kitazawa, N. R. Roberson, H. R. Weller, M. J. Jensen and D. R. Tilley, Bull. Am. Phys. Soc. 28 (1983) 650

30. Radiative Capture of Neutrons by ^{40}Ca*, C. Fitzpatrick, N. R. Roberson, H. R. Weller and D. R. Tilley, Bull. Am. Phys. Soc. 28 (1983) 649

APPENDIX IV

TUNL SEMINARS

1. Pier Paolo Delsanto, University of Puerto Rico (10/7/82)
   Natural Boundary Condition Methods in Nuclear Reaction Theory

2. Gerhard Randers-Pherson, Ohio University (10/12/82)
   Several Approaches to the Measurement of $^{12}C(n,n')3\alpha$

3. Ivo Slaus, Ruder Boskovic Institute, Zagreb, Yugoslavia (10/26/82)
   Charge Asymmetry and the Three Nucleon Force

4. J. de Boer, University of Munich (10/28/82)
   Sense of Rotation of Colliding Nuclei

5. Thomas B. Clegg, University of North Carolina at Chapel Hill (11/4/82)
   Beam Pulsing System Development at TUNL

6. John Kuehner, McMaster University, Hamilton, Ontario (11/11/82)
   The Use of Tensor Polarized Deuterons to Measure Spins and Parities of Nuclear Levels

7. George Walker, Indiana University (11/18/82)
   Kaon-nucleus Reactions

8. Douglas Beck, Massachusetts Institute of Technology (12/2/82)
   Measuring the Tensor Polarization (T_{20}) of the Deuteron via Elastic Electron Scattering

9. Everett Fuller, National Bureau of Standards (12/9/82)
   The Deuteron and Other Problems in Photonuclear Reactions

10. E. J. Ludwig, University of North Carolina at Chapel Hill (1/20/83)
    Investigation of Isospin Mixing in Light Nuclei

11. Jolie A. Cizewski, Yale University (1/27/83)
    Experimental Tests of Supersymmetries in the Os-Ir-Pt Nuclei

12. Gary Love, University of Georgia (2/3/83)
    Nuclear Structure Information from Polarization and Analyzing Power Differences in Inelastic Proton Scattering Experiments

13. Blayne Heckel, University of Washington (2/10/83)
    Investigations of Parity and Time-reversal Violations with Reactor Neutrons

Appendix IV

14. Donald R. Lehman, The George Washington University (2/17/83)
What Do We Learn About the Structure of ^{6}He and ^{6}Li From Three-Body Models?

15. S. M. Shafroth, University of North Carolina at Chapel Hill (2/24/83)
Metastable X-ray and Auger Electron Spectroscopy at TUNL

16. G. S. Hurst, Oak Ridge National Laboratory (3/10/83)
Weak Interactions and Single Atom Counting

17. G. M. Temmer, Rutgers University (3/24/83)
Electron Channeling Radiation

18. B. C. Clark, Ohio State University (3/31/83)
Dirac Phenomenology and Nucleon-Nuclear Interactions

19. John Farrell, Los Alamos Scientific Laboratory (4/1/83)
Physics of Comet Tails

20. Y. Abe, Research Institute for Fundamental Physics, Kyoto University (4/12/83)
Theoretical Aspects of Heavy Ion Resonances

21. Henry Weller, Duke University (4/14/83)
Neutron and Proton Capture Studies into ^{3}He, ^{3}H, and ^{4}He: Is There Evidence for Charge Symmetry Violation?

22. Christian Stoller, ETH, Zürich, and Stanford University (5/16/83)
Nuclear Sticking and K-shell Ionization in the Deep Inelastic U + U Collision at 7.5 MeV/amu

23. Conrad Knight, Duke University (5/26/83)
Radiation Safety at TUNL

24. Robert L. Rummel, Duke University (6/2/83)
TUNL Emergency Procedures

25. Jesse L. Weil, University of Kentucky (6/15/83)
Doppler Shift Attenuation Method for (n,n',γ) Measurements

26. Paul C. Colby, University of Wisconsin (6/16/83)
Investigation of the Asymptotic Normalization of the ^{3}He Wave Function

27. Thomas B. Clegg, University of North Carolina at Chapel Hill (6/21/83)
A Tutorial on Theory and Operation of The Lamb-Shift Polarized Source

28. Thomas B. Clegg, University of North Carolina at Chapel Hill (6/23/83)
Future Plans for Obtaining an Intense Polarized Source for TUNL

Appendix IV

29. Cynthia Gossett, University of Wisconsin (6/27/83)
Radiative Capture of Polarized Deuterons in the Region of the Giant Dipole Resonance in ^{16}O

30. Thomas McAbee, University of North Carolina at Chapel Hill (6/30/83)
The Spin-Spin Interaction and Polarized Targets

31. Roger C. Byrd, Duke University (7/7/83)
Isospin and Charge-Symmetry Studies in Light Nuclei

32. Calvin Howell, Duke University (7/14/83)
An Introduction to the VAX Interface and Data Taking Systems

33. Robert E. Shamu, Western Michigan University (7/21/83)
Dibaryon Resonances

34. Edward J. Ludwig, University of North Carolina at Chapel Hill (7/28/83)
Nuclear Radiation Detectors

35. David G. Haase, North Carolina State University (8/4/83)
Progress Report on the TUNL Cryogenic Polarized Target

36. George Walker, Indiana University (8/10/83)
Nucleon-Nucleus Reactions at Lower Medium Energies

37. George Walker, Indiana University (8/11/83)
Exchange Currents in Electro-Weak Nuclear Processes

APPENDIX V

GRADUATE DEGREES AWARDED

1. B. L. Burks, "Nuclear Spectroscopic Measurements Related to the Design of ^{79}Br, ^{81}Br and ^{87}Rb Solar Neutrino Detectors", Ph.D. degree, UNC-CH. Supervisor-E. J. Ludwig

2. C. M. Fitzpatrick, "Radiation Capture in the Giant Resonance Region of ^{41}Ca", Ph.D. degree, Duke. Supervisor-N. R. Roberson

3. J. L. Kendrick, "Design Testing and Calibration of a Proton Polarimeter", M. S. degree, UNC-CH. Supervisor-E. J. Ludwig

4. K. E. Nash, "Collimator and Shielding Design for Small-Angle Neutron Elastic Scattering", M. S. degree, UNC-CH. Supervisor-R. E. Anderson

5. R. O. Nelson, "Proton Resonance Spectroscopy in ^{28}Si and ^{30}P", Ph.D. degree, Duke. Supervisor-E. G. Bilpuch

6. J. F. Shriner, Jr., "Nuclear Resonance Spectroscopy in ^{45}Sc and ^{40}Ca", Ph.D. degree, Duke. Supervisor-E. G. Bilpuch

7. J. F. Wilkerson, "Isospin Mixing in Light Nuclei", Ph.D. degree, UNC-CH. Supervisor-E. J. Ludwig

8. M. C. Wright, "Neutron Capture in the Giant Dipole Resonance Region of ^{14}C", Ph.D. degree, Duke. Supervisor-N. R. Roberson

4.0 Lawrence Berkeley Laboratory

4.1 Bevalac Accelerator Complex

1. **What new science is being explored by this facility? What scientific opportunities are being exploited?**

   Answer: The Bevalac is unique in its ability to produce highly charged heavy ions at energies as high as 2.1 GeV/amu. In the realm of basic nuclear physics, this facility permits exploration of the behavior of atomic nuclei under conditions of extreme compression and high temperature such as existed previously only during the "big bang." Such studies are not possible with small projectiles such as protons, electrons, or light ions. The high energies and heavy projectiles from the Bevalac allow large amounts of energy to be deposited throughout the nuclear volume, raising the density to four times normal or more, and producing temperatures above 100 MeV (10^{12} degrees Celsius).

   Under these conditions, new states of matter are conjectured to be possible, including the "quark-gluon plasma." A major part of the Bevalac program is to explore such possibilities. In addition, the Bevalac offers unparalleled opportunities for producing and studying very neutron-rich nuclei by use of the "projectile fragmentation" method, and for studying the atomic physics of hydrogenlike and heliumlike uranium to test the theory of quantum electrodynamics. The facility is also used for studies using high energy heavy projectiles important for inertial fusion and space physics.

   Some of this latter research is being carried out in collaboration with NASA. Areas of current interest include (a) the development and calibration of high energy (greater than 1 GeV/amu) cosmic ray isotope detectors, (b) studies of electron capture and stripping in very heavy ions, and (c) fragmentation studies aimed at assuring the protection of personnel and sensitive electronics in space.

   Experiments at lower energies are conducted with intense heavy ion beams at the SuperHILAC (the Bevalac injector). Active areas of research include (a) the study of reaction mechanisms peculiar to heavy ions, especially the deep inelastic reaction; (b) the atomic physics of highly charged heavy ions, including very rigorous tests of quantum electrodynamics and studies of electron capture processes; (c) the study of level schemes (and particularly electromagnetic moments) of nuclei, using multiple Coulomb excitation and inverse reactions to obtain high recoil velocities for Doppler shift and transient field measurements; and (d) the production and study of very heavy actinide and transactinide isotopes, and of very neutron-rich and neutron-deficient nuclides throughout the periodic table.

   The high energy heavy ions available only at the Bevalac are also useful in several fields of medical and biophysical research. As as example, researchers exploit particles with charges ranging from +2 to +92 to determine fundamental relationships between linear energy transfer, track structure, and radiation damage in model biological systems. Current biophysics research is testing hypotheses and developing models for chemical and molecular damage that results in such biological effects as cell death, mutation, and cancer induction. Biological responses to charged particles provide predictive models for radiation damage, in turn allowing assessment of radiation hazards in terrestrial and space environments.

The unique physical and biological properties of charged particles are also exploited in human radiation therapy experiments. Dose can be localized at the site of the tumor, and oxygen-starved tumor cells are preferentially killed. Experiments test the hypothesis that local cancer control can be better achieved with heavy ions than with conventional radiotherapy. An additional benefit of therapy with highly charged particles is that delivery of the prescribed dose to the tumor volume can be experimentally verified by use of radioactive beams and positron emission tomography. Over 300 patients have received radiation therapy in clinical trials at the Bevalac.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

Answer: The ion mass and energy ranges of the Bevalac are currently unique in the world. Uranium beams are available at GSI in Darmstadt, West Germany, at an energy of 20 MeV/amu, far below the 960 MeV/amu available at the Bevalac. Light ions, carbon, and neon are available at the synchrophasotron in the USSR at somewhat higher energies than the Bevalac, but at very low intensities. In the U.S., the SuperHILAC remains the only accelerator capable of producing beams of ions heavier than mass 150 at energies above the Coulomb barrier.

Several heavy ion facilities are currently under construction:

- Michigan State Phase II will eventually produce beams of uranium at energies of a few tens of MeV/amu, still well below Bevalac energies. Light ions will reach energies of 100 to 200 MeV/amu, also below Bevalac energies.

- Saturne II at Saclay, France, is just installing a heavy ion capability with an EBIS-RFQ injector combination. Maximum mass is expected to be 84 (krypton) at a few hundred MeV/amu. This facility will not exceed Bevalac specifications.

- The Brookhaven Tandem-AGS transfer line will give the AGS ions at energies of 15 GeV/amu, substantially higher than the Bevalac. However, mass will be limited to about 32 (sulfur).

- Very high energy (200 GeV/amu) oxygen ions will be available in early 1986 in the SPS at CERN, when a new injector, built jointly by LBL, GSI, and CERN, is installed.

Planned facilities include two in Europe and one in the U.S.:

- SIS-18 at GSI will give this German facility capabilities essentially identical to (but not greater than) the Bevalac. SIS-18 is expected to be on line in 1989.

- MIMAS, a new storage ring/injector for Saturne will push mass to the range of 100 to 150, still below Bevalac capabilities.

- In 1983 the Nuclear Science Advisory Committee updated A Long Range Plan for Nuclear Science and concluded that a high energy nuclear collider (capable of producing uranium beams of 30 GeV/amu or more) should be the next major U.S. facility. Several institutions have expressed interest in building such a collider.

In summary, the Bevalac, as a source of relativistic uranium ions, will remain a unique facility for perhaps another 10 years. Although facilities are on the drawing boards to meet or exceed current Bevalac capabilities, none is expected to be operational this decade.

3. **What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?**

Answer: The most important instrumentation for Bevalac nuclear physics, much of it unique, includes the following:

- The Streamer Chamber, which produces three-dimensional images of nuclear interactions and allows direct measurements of 100 or more secondary charged particles. The Streamer Chamber is supplemented by an array of 396 scintillators, each with pulse-height and time-of-flight readouts via a large-scale digitizer (LSD).
- The Plastic Ball-Wall, a fully electronic detector with over a thousand individual particle detectors covering 96% of the entire sphere. Over 4000 individual parameters are read out by computer, and all detectors are automatically calibrated by a laser operating during the experiment.
- HISS, a superconducting magnet producing a field of 3 T over a 3-m-diameter, 1-m-wide gap. HISS includes large area time-of-flight and tracking detectors for reaction products.
- MUSIC, a multiple-sampling ionization chamber capable of identifying the charges of individual nuclear fragments as heavy as uranium.
- Instrumentation used extensively for cosmic ray calibration experiments and other work in collaboration with NASA, including (a) a simple 0° spectrometer system for delivering beams of any particle-stable isotope, (b) beam monitoring detectors for atomic numbers up to 92, (c) instrument positioners, (d) computer-controlled energy degraders and targets, and (e) a PDP 11/45-CAMAC data collection system.
- A Low-Energy Beam Line (LEBL), which provides unique opportunities for nuclear physics in the interesting "intermediate energy" range by providing heavy ion beams at 20 to 200 MeV/amu.
- A general purpose beam line (Beam 30) containing several magnetic spectrometers for specialized purposes, including the two-armed spectrometer system (TASS) and the large-acceptance universal pion spectrometer (JANUS).
- Secondary beams of unstable nuclei such as helium-6, carbon-11, and fluorine-18 with sufficient intensity for nuclear physics and biomedical studies.
- A data acquisition network featuring three VAX-11/780's and ten "front-end" computers (either PDP-11's or VAX-11/750's).

Instrumentation at the SuperHILAC includes:

- The Small-Angle Separation System (SASSY), a spectrometer used to search for new isotopes, including superheavy elements.
- The On-Line SuperHILAC Isotope Separator (OASIS), which separates products that are then ionized, accelerated, and transported to a low-background counting area.
- The COULEX (Coulomb excitation) cave, which is used for gamma-ray studies of high spin states in nuclei.
- An irradiation station used to generate materials for off-line analyses.
- The 60-inch scattering chamber, used for nuclear reaction studies of particle decay modes and mass distributions in heavy ion reactions.

This facility is specially designated for outside users. Instrumentation used solely for medical and biological research are the following:

- The Wobbler, a pair of dipole magnets that delivers a large (up to 30 cm diameter) radiation field of uniform dose for radiotherapy.
- The Positron Emitting Beam Analyzer (PEBA), a 128-detector device used to provide a three-dimensional reconstruction of the stopping region of heavy-ion beams used in radiotherapy.
- A Schimmerling time-of-flight device, which is used to measure particle velocity and dE/dx as means of characterizing heavy ion beams.
- The Rossi chamber, a microdosimeter that characterizes energy transfer in tissue by simulating the process in a model gas.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer:

RESEARCH HIGHLIGHTS

Bevalac Physics. In the period since 1982, Bevalac physics research has been highlighted by the production of uranium atoms fully stripped of their 92 electrons--probably the first time bare uranium nuclei have existed anywhere in the universe. These (and other) highly charged heavy nuclei have now been used in a number of important experiments, including the following:

- Studies of the energy loss of fast uranium ions in matter. These studies indicate that a single ion can deposit as much as 30 GeV over a track length of only 1 mm--a finding of obvious interest for inertial fusion.
- Observations of nuclear matter compressed to four times normal density, verified by direct measurement of the energy stored in compression and of the effects produced when the stored energy is later released.

- Observation of nuclei heated to more than 100 MeV (roughly 1012 degrees Celsius) and the study of chemical reactions, within the nuclear volume, between particles created by the heat.
- Observation by the Hanbury-Brown, Twiss method of intensity interferometry of the size of the nuclear volume from which created particles such as pions are emitted.
- Observation of hydrodynamical effects in nuclear collisions, indicating that macroscopic theories of nuclear reactions are applicable and that the interacting nuclei behave collectively, not as assemblies of individual neutrons and protons.
- Demonstration that nearly all the energy in a 2-GeV/nucleon projectile can be "stopped" in a large target nucleus. This suggests that conditions even more extreme that those we have observed might be achievable if higher-energy beams of uranium nuclei were available.
- Determination of an upper limit for the production of fractionally charged particles, predicted by some to be possible in energetic nucleus-nucleus collisions if a "quark-gluon plasma" is created.
- Observation in nuclear emulsions (not yet confirmed by independent means) of anomalous projectile fragments ("anomalons") that interact much more strongly than conventional nuclear theories allow.

Cosmic Ray and Space Physics. Our systematic study of nuclear fragmentation processes at the Bevalac has provided essential cross sections for cosmic ray propagation calculations, revealed the importance of Coulomb interactions in relativistic nuclear fragmentation, and led to the development of a versatile instrument for particle identification, now being used in both cosmic ray and nuclear physics experiments. An example of the usefulness of this newly developed particle identifier was provided by the University of Chicago IMP satellite experiment, which provided a positive measurement of the astrophysically important 10Be/NBe ratio.

Relativistic gold beams have been used to verify measurements of the charge composition of very heavy cosmic rays, and iron and uranium beams have been used in a program to develop new pyroelectric detectors and position-sensitive drift chambers based on primary and avalanche electrons. In addition, we have provided preflight calibration of many LDEF passive detectors, which should help remove many charge-resolution uncertainties for these devices.

SuperHILAC. Much of the work at the SuperHILAC has been aimed at determining the nature of the equilibration of energy, mass, charge, and angular momentum in deep inelastic processes. In particular, experiments have shown the effects of fluctuations on the nuclear alignment and the gradual excitation of a number of two-body vibrational and rotational modes, and on the evolution of energy transfer in asymmetric systems from a nearly equal division of energy to the thermal equilibrium value proportional to the mass.

Other studies have shown the existence of pre-scission particles and the connection between the evaporation of heavier particles and asymmetric fission. The production and study of hydrogenlike and heliumlike ions have given the most rigorous tests yet of quantum electrodynamics in a strong electric field.

Doppler-shift studies at the SuperHILAC have given the first experimental evidence that very collective rotational bands exist at high spin in nuclei. Another study showed for the first time that the enormous transient magnetic field acting on highly charged recoil ions in ferromagnetic materials (iron and cooled gadolinium) does not increase linearly with recoil velocity, but passes through a maximum, or at least saturates. Also, by use of the deep-inelastic reaction with heavy neutron-rich projectiles, a large region of neutron-rich nuclei throughout the periodic table has been made available for study.

Biomedical Research. The relationship between linear energy transfer and cell killing has been shown to be different for in-vivo and in-vitro model systems, owing to different target volumes and radiation sensitivities. Further, comparisons between results for cell killing, neoplastic transformation in vitro, and cancer induction in experimental animals have shown that carcinogenic risk remains high at linear energy transfer levels where cell killing is low. Predicted relationships between linear energy transfer and carcinogenesis have thus not been confirmed, and new predictive models must be developed.

Radiobiology experiments have provided new information on the response of various tumor model systems and normal tissues to heavy charged particles. Radiosensitivities have been defined for intestine, skin, testes, bone marrow, lens of the eye, spinal cord, and lung under conditions of single and fractionated exposures. This information is essential for radiotherapeutic applications of heavy charged particles.

Three hundred patients have received partial or full-course radiation therapy in clinical trials. These trials were designed to determine human tissue tolerances under clinical conditions and to provide essential preliminary data on local tumor control.

ANTICIPATED STUDIES

During the remainder of FY 1984 and in FY 1985, Bevalac physics experiments will continue to explore nuclear collisions between the heaviest elements. Evidence will be sought for the "sidesplash" of particles predicted by hydrodynamical theories to occur in head-on collisions of large nuclei. Study of the fragmentation of very heavy projectiles will begin, using new detectors now under construction. It is anticipated that a large variety of previously unobserved isotopes will be discovered. A new method of studying nucleus-nucleus collisions-- the observation of "direct" electrons--will also be explored.

A new field of nuclear physics studies, using unstable nuclei previously unavailable as targets or projectiles, will begin to be developed. The first experiments will measure nuclear radii and magnetic moments. Using a new beam line, systematic study of the production of kaons and antiprotons, the latter far below the threshold for normal processes, will also begin. Following planned upgrades to increase beam intensity, spectroscopy will also be possible on hydrogenlike and heliumlike ions to further test the theory of quantum electrodynamics. Finally, definitive electronic experiments to confirm or disprove the existence of "anomalons" will be carried out: if the phenomenon is confirmed, much emphasis will be placed on their study.

Collaboration with NASA will also continue. Among its aims are (a) to provide a new geological dating tool by measuring production cross sections for argon fragmentation products, (b) to calibrate Pioneer 11 Jupiter probes to verify the presence of a heavy ion component in Jupiter's radiation belts, (c) to provide isotope production cross sections from 100 to 2000 MeV/nucleon from oxygen, neon, argon, and iron beams (these are necessary to understand cosmic ray propagation and source abundances), (d) to study cosmic ray effects on the fine guidance system of the space telescope, and (e) to continue development of fiber- optic position/tracking detectors, pyroelectric detectors, and high-energy isotope telescopes for cosmic ray and nuclear science programs.

Biomedical research will continue on the relationships between charged particle track structure and biological damage. Based on results from experiments conducted with particles ranging in charge from +20 (argon) to +92 (uranium), a generalized model of radiation damage will be formulated that will have broad application to other kinds of external radiation, including neutrons, and radiation from internally deposited radioisotopes. New data obtained with repair-deficient human cell cultures will facilitate development of predictive models relating DNA damage and repair to cell killing, mutation, and neoplastic transformation, all in relation to charged-particle track structure. New information will be available on carcinogenic risk and other deleterious late effects such as vascular injury in the brain and other tissues, based on experiments with mice and larger experimental animals. Randomized Phase III radiotherapy trials on selected tumor sites will begin, and early clinical impressions regarding the efficacy of charged particles for local tumor control may be available.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: In 1982 a major improvement project was completed, giving uranium ion capability to the Bevalac. This project included a new injector for the SuperHILAC, providing greater intensities of the heavier ions, and a new vacuum system for the Bevatron, assuring survival of partially stripped ions during the acceleration process.

This new capability has tremendously increased the range of operational possibilities, which now extends from high intensities of the heaviest ions, either stripped $^{68}\text{U}^{+}$ or unstripped $^{40}\text{U}^{+}$ at the SuperHILAC exit, to good intensities of molecular hydrogen $^{2}\text{H}^{+}$--the most efficient source of protons for this facility. The total inventory of ions and charge states numbers well above 50, at least a threefold increase over pre-upgrade operation.

Other improvements in progress or in the final planning stages include:

- A local injector upgrade. By the addition of an RFQ, the Bevatron local injector is being enhanced to produce beams of ions up to mass 40. This will meet the needs of the radiotherapy program and allow for rapid ion-switching, thus completing the efforts of the Fast Switch Program. This program, aimed at maximizing beam utilization by integrating the radiotherapy and nuclear science programs, calls for completely changing the accelerator configuration (beam ion, energy, and target area) in a minute or less, so as to effectively use the setup time between patients for continued nuclear science experimentation.

- Transfer line and external beam area upgrades. Planned for the next two years, these upgrades will improve efficiency and capabilities for new beam species, including study of kaons, antiprotons, and nuclear structure.

- A new ion source for the SuperHILAC. A new technology developed by the Bevalac R&D group permits production of extremely high currents of heavy metallic ions (several hundred milliamps of uranium 5+ ions have been extracted into a low emittance beam). This represents about a hundredfold improvement over present source technology. The new source, to be installed around late 1985, will greatly increase available beam currents of these ions at both the SuperHILAC and the Bevalac.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, Capital Equipment, General Plant Projacts, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer: In the three tables below, FY 1985 figures are taken from the President's budget.

Nuclear Physics - Bevalac Operations: All entries are in thousands of dollars; the source of all funds was Heavy Ion Nuclear Physics, except as noted.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Operations	13,565*	14,503*	14,474	17,270**	17,625
Capital equip.	383	687	765	382	500
Accel. improvements	425	300	1,100	700	1,200
In-house energy mgmt.	0	0	0	194	726

* Includes Life Sciences and Nuclear Medicine Applications support of Bevalac operations: $2,567,000 in FY 1981 and $2,714,000 in FY 1982.

** Includes Medium Energy Nuclear Physics support of Bevalac operations: $1,000,000 in FY 1984.

Nuclear Physics - Research: All entries are in thousands of dollars; the source of all funds was Heavy Ion Nuclear Physics.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985 (est)
In-house research	3,759	4,088	4,152	5,352	5,560
Out-of-house research	0	75	190	285	290
Total research	3,759	4,163	4,342	5,637	5,850
Capital equip.	918	1,003	917	1,138	2,241

Biomedical Research: All entries are in thousands of dollars; funding sources are Life Sciences Research and Nuclear Medicine Applications, and Environmental Research and Development.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985 (est)
In-house research	821.9	880	914.4	884	805
Out-of-house research	0	0	0	0	0
Capital equip.	195.8	137.2	81.8	89.1	245

7. How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: No funding has been provided or is expected from other agencies for nuclear physics. Funding for biology and medicine is summarized below, in thousands of dollars.

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985 (est)
In-house Research					
NIH	3,007.9	3,552	3,975	4,316	4,483.2
NASA	304.3	320.6	358.5	432.6	456
Capital equip. (NIH)	119.6	85.9	78.6	45	8
Other NIH*	124.6	1,319.1	1,344.2	981.4	700

* Medical Accelerator Design Study.

8. For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.

Answer:

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985 (est)
Bevalac Operations	196	178	159	183	175
Nuclear Phys Research	60	55	52	64	63
Biomedical Research	14	12	12	11	9
In-House Research					
NIH	29	37	40	42	40
NASA	3	3	4	5	5
Other NIH	1	15	15	8	4

9. What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?

Answer: For the period FY 1981 - FY 1985, actual and estimated utilization of the LBL Bevalac complex is given in the following table:

BEVALAC FACILITY UTILIZATION

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Beam Hours for Research	2201	1886	3083	3900	3500

For the Bevalac complex we estimate full utilization to be 6000 beam hours for research per year.

10. **For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?**

Answer: In the table below, experiments begun or completed in a fiscal year are also included among the experiments "run."

	FY 1981	FY 1982*	FY 1983	FY 1984**	FY 1985**
Bevalac					
Started	25	13	27	22	20
Run	40	31	43	42	40
Completed	33	13	15	18	20
SuperHilac					
Started	16	36	21	20	30
Run	16	36	24	38	30
Completed	14	21	3	38	30

* Budget rescission and power cost escalation limited operation in FY 1982.
** Estimated figures based on backlog and operating projections.

11. **What is this facility's user policy?**

Answer: Time is available at the Bevalac and SuperHILAC for any qualified researcher who is able to submit and successfully defend an experiment proposal to the Program Advisory Committees for the Bevalac complex. Three committees, reporting to the Laboratory Director, have been constituted, one each for Bevalac nuclear science, SuperHILAC nuclear science, and Bevalac biology and medicine programs. (See question 13 for elaboration.) In addition, a small percentage (5-10%) of the research time is available to the Scientific Director of each discipline to allocate as s/he deems appropriate. The three Scientific Directors implement the decisions of the Laboratory Director by ensuring that accelerator emphasis is placed on the most urgent, timeliest, and most productive of the approved experiments. Furthermore, the Scientific Director acts as the scientific focal point for the user community in user-facility relations.

Each of the three disciplines also has a user liaison officer, who is a practicing scientist. The liaison officer's duties include helping to stage and execute experiments, primarily for non-LBL users. The liaison officer is also charged with maintaining a user's organization, the vehicle through which users communicate with LBL management on matters of interest in the scientific community. This input is encouraged by facility management, which uses it to direct effort in implementing the various research programs.

Research time at the accelerators is scheduled among approved experiments in the estimated order of scientific priority and the readiness of the experimental group. No charges are made for accelerator time.

Miscellaneous goods and services pertaining to the experiment are available at the Laboratory's cost. These include engineering, shop use, instrument maintenance, supply items from the storehouse, etc. Experimenters bringing their own equipment must ensure that the equipment meets LBL safety standards before any tests are done or any experiment begun. Operations and support services are oriented toward the experiment in progress as the highest priority task.

12. For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?

Answer: The policy of the Bevalac complex does not include provision for reimbursable research. It is estimated, however, for the period involved, that improvements made by some non-LBL research organizations to various experimental areas have had a total value of about $250,000.

13. What is the mechanism by which specific research proposals for experiments at the facility are considered?

Answer: Three program advisory committees, one each for Bevalac nuclear science, SuperHILAC nuclear science, and Bevalac biology and medicine, make recommendations to the Laboratory Director concerning the disposition of submitted research proposals. Each committee is composed of five to seven internationally known experts in their fields, who themselves are from institutions in the United States, Canada, Japan, and Europe. They meet semiannually to review research proposals and to submit to the Director their recommendations (a) for approval, rejection, or reconsideration of specific proposals and (b) for the general direction of research in each of the disciplines.

Users and potential users are sent a call for proposals approximately two months prior to Bevalac's program advisory committee meetings. Contained in the call is a standard proposal form asking for the nature of the research, the specific aims of the proposed experiment, the equipment to be used, and the estimated accelerator resources required to accomplish the experiment. These calls for proposals are circulated to universities and laboratories around the world.

Approved proposals are put on the accelerator operating schedule at the earliest possible time, consistent with the Scientific Director's assignment of priority and the researcher's readiness to do the experiment.

14. How many research proposals have been submitted over the past five years, and how many of these have been approved?

Answer:

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
Bevalac					
Proposed	41	27	47	60	39
Approved**	32	20	42	55	34

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
SuperHILAC					
Proposed	20	20	45	29	36
Approved**	20	19	43	29	34

* Through March 1, 1984.
** Typically, fewer hours are allotted than originally proposed. For the Bevalac, about 50% of the total time proposed is eventually approved.

15. How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?

Answer:

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
Bevalac	118	127	94	130	116
SuperHILAC	37	40	74	74	80

* Through March 1, 1984.

16. How many industrial researchers have utilized the facility over the past five years?

Answer: Owing to the nature of the facility, nearly all proposals submitted to the Program Advisory Committees involve basic research, rather than applied industrial research. Only one industrial researcher has used the facility in the last five years.

17. How many researchers from foreign institutions have utilized the facility over the past five years?

Answer:

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
Bevalac	30	45	28	106	43
SuperHILAC	21	16	35	42	30

* Through March 1, 1984.

18. How many researchers from other agencies have utilized the facility over the past five years?

Answer:

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
Bevalac					
Other agencies**	24	22	28	28	29

	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984*
SuperHILAC					
Other agencies**	13	13	7	5	9

* Through March 1, 1984.
** NASA, NSF, NIH, U.S. Navy.

19. What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer:

Future development possibilities include:

1. Improvement of beam utilization by fast switching from one beam line to another with change of ion and energy. The hardware for this has already been acquired. The end result will be a more effective utilization of the operating funds.

2. Improvement of Bevalac beam intensity by modifications of the SuperHILAC injector. Improvement by a factor of 10 to 100 is foreseen as possible, at a cost of $2.7 million. Such improvements would open up new classes of experiment not currently possible, especially with secondary beams of unstable nuclei, and would allow study of rare events that are now count-rate limited. Spectroscopy of hydrogenlike and heliumlike ions would permit rigorous tests of quantum electrodynamics.

3. Addition of a new beam line for the study of kaons and antiprotons, as well as for improved nuclear structure studies with the lower energy beams. This is planned for FY 1984 and it will improve the effectiveness of the facility.

4. Development of the HISS detector array. Such development will enable the full potential of nuclear physics with fast heavy ions to be explored. The Phase II detectors (12 planes of drift chambers 5 m by 2 m) will provide very large solid angle coverage with measurement and identification of charged particles over a large dynamic range. Other detectors--for neutrons or photons, for example--will also be needed. These developments can be carried out over a period of 2 to 3 years within the present level of capital equipment support.

5. Installation of a "dilepton spectrometer" for study of electron pairs produced in nucleus-nucleus collisions. Such electron pairs, believed to be formed in quark-antiquark collisions within the nucleus, are considered to provide the most effective signature of quark-gluon plasma formation, predicted to occur at sufficiently high beam energies. A detailed proposal is in final stages of preparation for FY 1985 - FY 1987 funding at a total capital cost of approximately $10 million. The detector design has developed over several years and has involved the collaboration of many university users of the Bevalac.

6. A large-solid-angle detector more elaborate than the existing Plastic Ball- Wall. Preliminary physics goals for such a detector are being discussed. It is expected that detailed plans will take about two years to develop and that funds will be requested for the FY 1987 - FY 1988 period, at a total cost of about $10 million.

7. Experimental results with very heavy beams from the Bevalac have indicated that extremely interesting physics can be studied at energies slightly higher than those available now. At such energies, we may be able to reach the high-baryon-density regime, thus achieving energy densities and temperatures high enough to create a plasma in which quarks are deconfined. We are exploring the possibility of reaching this regime by building on the base of existing hardware. One possibility is to use the Bevalac as an injector for two experimental storage rings. Uranium ions at about 400 MeV/amu could be injected into each ring and accelerated to about 3 GeV/amu, providing energies equivalent to about a 30 to 50 GeV/amu fixed-target machine. This pair of rings, called the Mini-Collider, could be built from 4- to 6-T magnets, probably of the "2 in 1" design. It would measure approximately 40 by 60 m, would require only limited shielding, and could be located in the Bevalac external beam area with minimum impact on existing experimental facilities. The luminosity achievable in this collider would be around 3 x 1023 cm-2 sec-1 (limited by intrabeam scattering and not by the brightness of the injector system) and would yield about one central collision every 3 seconds, an acceptable data rate considering the complexity of the interactions and the information content of each reaction. This concept is in the exploratory stage and has not yet been costed.

20. Please provide a copy of the facility's latest annual report.

Answer: Attached are the 1982 annual reports for the Accelerator and Fusion Research Division, the Nuclear Science Division, and the Biology and Medicine Division. Pages I through 17 of the AFRD report cover Bevalac operations; the NSD and Biomed reports include more detailed research results, together with results from other facilities. **(Note: Excerpts from these reports follow.)**

ANNUAL REPORT

ACCELERATOR & FUSION RESEARCH DIVISION

Fiscal Year 1982

(October 1981 - September 1982)

Scientific Editor: R.K. Johnson
Production Editor: C. Bouret

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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ACCELERATOR OPERATIONS

INTRODUCTION

The Accelerator and Fusion Research Division operates the Bevalac Complex as a national research facility for studies in high-energy, heavy-ion physics, nuclear physics, nuclear chemistry, biomedicine, biophysics, and astrophysics. The Bevalac is unique in the opportunity it provides for the study of collisions between nuclei at energies high enough to convert nuclear matter into hadronic matter in which protons, neutrons, their excited states (e.g., delta resonances) and free pions all coexist. One third of its time is devoted to biomedical research, including a trial program of cancer therapy. At low energy, the SuperHILAC has been the U.S. vanguard of discovery of new heavy elements in strong competition with a Soviet effort at JINR, Dubna, and, more recently, a West German effort at GSI, Darmstadt. This portion of the Bevalac Complex is maintaining its primacy among U.S. installations for the delivery of ions with $A > 100$ to elucidate many of the global features of the fusion, deeply inelastic (damped), and fission reactions that typify nuclear phenomena in this energy range.

The SuperHILAC, an Alvarez-type linear accelerator, provides heavy-ion beams of lithium through uranium at energies from below 1 to 8.5 MeV per nucleon. Its three injectors can supply three different ion species to five different beam lines on a timesharing basis; that is, the beam is pulsed 36 times each second, and these pulses may be apportioned in any desired ratio between three different ion beams and any number of different energies. Normal operation involves the use of 32 pulses/second of a heavy-ion beam by the principal research group at the SuperHILAC, the sending of 2 pulses/second of a second ion beam to the Bevatron for further acceleration to relativistic velocities (this combined operation is called the Bevalac), and the use of 2 pulses/second of either beam—at a different energy if desired—for a parasitic experiment at the SuperHILAC. The SuperHILAC has 11 experimental areas.

The Bevatron is a weak-focusing positive-ion synchrotron that can accelerate heavy ions from either the SuperHILAC or a local injector to any energy between 40 MeV and 2 GeV per nucleon. The delivery rate is 10 to 15 pulses per minute, dependent on the operating mode. Beam sharing at the Bevatron is accomplished by dividing a specific ion beam at a given energy between two major branches of the beam delivery system on a particular Bevatron pulse, or by diverting the beam on a pulse-to-pulse basis from one target area to another.

Continual effort is given to improving the accelerator complex, both in machine operation and experimental facilities, so that it remains at the forefront of scientific investigation.

OUTSIDE USER SUPPORT

The focus of outside user support for the Bevalac Complex is the Accelerator Research Coordination (ARC) Office. Additional technical support is often required by outside experimenters to increase their research productivity. Ultimately, the entire Accelerator Operations Group is dedicated to serving the needs of Bevalac-Complex researchers, but a core of individual technicians, computer specialists, and scientists have the primary responsibility for such assistance. Duties of these support personnel include designing or modifying beam lines to achieve specific performance characteristics, designing and interfacing data acquisition systems, and installing and maintaining sophisticated research equipment.

For Bevalac users, the primary staff for nuclear physics research support consists of H. Crawford, F. Bieser, and R. Wada (scientific, beam lines), J. Porter (engineering, cryogenics), and H. Pugh (Scientific Director). The Bevalac biomedical community is assisted by W. Chu (physics, beam lines), T. Criswell (radiotherapy, computers, instrumentation), J. Howard (radiobiology), and E. J. Ainsworth (Scientific Director). At the SuperHILAC, principal staff contacts for user support are R. McDonald (physics, beam lines), C. Maples (data acquisition), E. Potter (supplies, coordination), W. Elwood (technician), and R. Diamond (Scientific Director).

During this period, two new facilities were created for guest experimenters. Badly needed staging areas were set up adjacent to the Bevalac to facilitate setup work by outside users. In addition, some effort has been made to address the problem of on-site user housing. Although space at LBL remains limited, we are just finishing the implementation of a 4-bed temporary user housing trailer near the experimental areas. In addition, support has been provided for the HISS facility in terms of engineering help for the cryogenic system associated with the superconducting dipole.

Long-range scheduling is performed by an ARC Office staff committee, which periodically sends notices to all users. The immediate operating program is arranged in weekly scheduling meetings; every effort is made to accommodate users' preferred running schedules.

The Bevatron/Bevalac and SuperHILAC Users Associations communicate user concerns to the accelerator operations staff. These groups also hold annual meetings to share research results and discuss future directions. The governing body (Executive Committee) of each group is given in Table 1.

Proposals for research time are reviewed twice a year by Program Advisory Committees (PAC's). Members are generally chosen from among experts in heavy-ion research who may be involved in LBL experiments but are not major facility users. There is one PAC for the SuperHILAC (Table 2) and one each for the nuclear science and the biology and medicine programs at the Bevatron/Bevalac (Table 3). These expert panels recommend the allocation of research hours to the LBL Director, and, as a rule, their recommendations are implemented.

LBL's Nuclear Science Division appoints a Scientific Director for each accelerator to provide leadership for the nuclear science research on the floor and to coordinate long-term improvements. Howel Pugh now holds this post at the Bevalac, as does Richard Diamond at the SuperHILAC. In addition, the Biology and Medicine Division appoints a Scientific Director (presently E. John Ainsworth) for its accelerator-based research. The Scientific Directors may allocate 10% of the research hours on a discretionary basis.

Table 1. Membership in the Users Association Executive Committees.

SuperHILAC	Bevatron/Bevalac
M. Blann, LLNL	S. Curtis, LBL, Chairman
D. Cline, U. of Rochester	R. Poe, U.C. Riverside
R. Diamond, LBL	J. Slater, Loma Linda U.
R. McDonald, LBL	K. Wolf, Argonne National Lab.
A. Mignerey, U. of Maryland	
	E. Ainsworth, LBL (ex officio)
J. Cerny, LBL (ex officio)	J. Cerny, LBL (ex officio)
H. Grunder, LBL (ex officio)	H. Grunder, LBL (ex officio)
	H. Pugh, LBL (ex officio)

Table 2. Program Advisory Committee for the SuperHILAC.

D. Fossan (Chairman) State U. of NY, Stony Brook	J. Randrup, LBL
S. Datz, Oak Ridge Nat'l Lab.	M. Zisman, LBL (exec. secretary)
C. Gelbke, Michigan State U.	J. Cerny, LBL (ex officio)
J. Hardy, Chalk River Nuclear Lab.	H. Grunder, LBL (ex officio)

Table 3. Program Advisory Committees for the Bevalac

Nuclear Science	Biomedical
H. Feshbach, M.I.T. (Chairman)	M. Bagshaw, Stanford Med. Ctr.
R. Klapisch, CERN	R. Durand, Johns Hopkins Oncology Center
D. Scott, Michigan State U.	R. Fry, ORNL
P. Siemens, Texas A&M U.	W. Schimmerling, LBL
E. Vogt, U. of British Columbia	P. Todd, Penn. State U.
W. Wenzel, LBL	E. Ainsworth, LBL (exec. secretary)
T. Yamazaki, U. of Tokyo	
H. Pugh, LBL (ex officio)	E. Alpen, LBL (ex officio)
	H. Grunder, LBL (ex officio)

1982 OPERATIONS

Final touches were made early in 1982 to the High Intensity Uranium Beams Project, an improvement program in which a low-temperature high-vacuum pumping shell was inserted into the Bevatron, and a high-intensity, low-charge-state injector (ABEL) was added to the SuperHILAC. (See the previous annual report, LBL-14230, for a description of these improvements.) These facilities were brought on line in March for the research program, and in September of 1982 a full-energy (960 MeV/N) uranium beam was delivered to an emulsion experiment at the exit of the Bevalac (Figure 1).

Operations for FY 1982 were limited to five and a half months, but during that time major tests of heavy-ion acceleration were done, and the repertoire of relativistic ions delivered was expanded to include ^{84}Kr, ^{93}Nb, ^{129}Xe, ^{139}La, ^{197}Au, and ^{238}U. Table 4 details all the delivered ions and their intensities. For the most part, experimenters made use of carbon and neon, with protons and silicon also getting a substantial percentage of attention. Iron is becoming a popular ion, especially for the cosmic ray physicists and NASA-associated experimenters.

Beam time at the Bevalac is still divided approximately two thirds for the nuclear science program and one third for the radiotherapy and biology program (Table 5). Radiotherapy trials continued during 1982 using neon as the primary ion of choice, with some initial exploration into silicon treatments. Biology efforts this year were directed toward investigations of the effects of several ions: neon, silicon, argon and iron.

At the Bevalac the rewards of the recent uranium upgrade were almost immediately evident. Some programs that have been waiting years for heavy ions, those above iron in atomic mass, could now be scheduled for operation on the improved Bevalac. Budgetary constraints limited Bevatron operation to half of the maximum guide field strength, or about half the maximum achievable energy of a heavy-ion beam. Even with this rather severe restriction, time was well subscribed, the Bevalac program was full, and interesting science was produced. Nuclear science operation in 1982 at the SuperHILAC also benefited from the fact that the third injector (ABEL) was in operation and provided higher intensity heavy-ion

Table 4. Ion species and intensities delivered to Bevalac experimenters during FY 1982.

Ion	Intensity[a]	Ion	Intensity[a]
Hydrogen-1	2×10^9	Calcium-40	4×10^7
Helium-4	5×10^8	Iron-56	3×10^7
Carbon-12	2×10^9	Krypton-84	1.5×10^6
Neon-20	5×10^9	Niobium-93	1.5×10^6
Silicon-28	1×10^9	Xenon-129	1.5×10^6
Argon-40	5×10^8	Uranium-238	2×10^4

[a] Particles per pulse in the external beam channel.

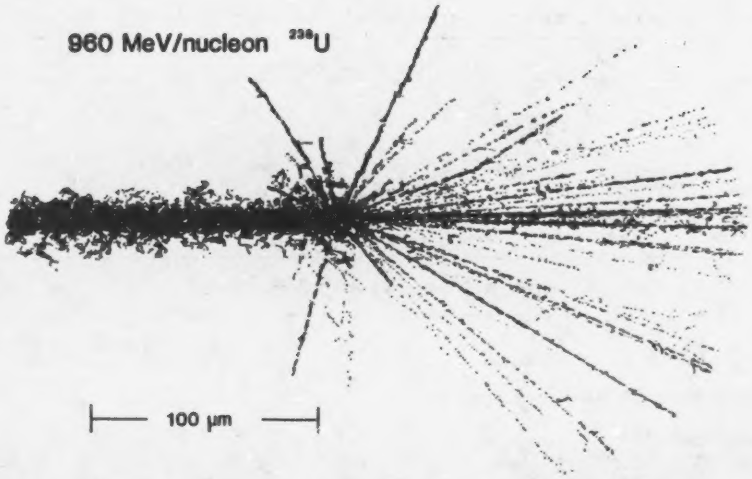


Figure 1. Microprojection drawing of 960 MeV/N ^{238}U in nuclear research emulsion. Seen entering from the left, the uranium beam nucleus interacts with a target nucleus, e.g., Ag or Br, of the emulsion. The nuclear collision results in virtually complete disintegration of the uranium nucleus, whose (light) fragments are emitted in the forward cone. The dark tracks at larger angles are remnants of the target nucleus. (XBL 829-11834)

beams than had been produced ever before for the low-energy heavy-ion program. Also in support of the low-energy experimental program, 2 grams of ^{48}Ca material have been loaned to GSI, Darmstadt as part of the joint LBL/GSI program to search for superheavy elements.

In the Bevalac experimental area, a long-term project, the Heavy Ion Spectrometer System (HISS), was brought into operation. This facility consists of a large dipole magnet having a cryogenically cooled set of superconducting coils and several sets of large-scale particle detectors (Figure 2). The active magnetic volume of the dipole, which is approximately 2 m in diameter by 1 m high, is designed for a field of about 3 T. Measured fields by the end of 1982 were about 2 T. Most of the magnetic volume is bounded by a vacuum chamber for which thin plastic windows were developed.

Experiments performed so far in the HISS spectrometer include carbon fragmentation by Greiner *et al.* of LBL, and correlation studies by Nagamiya *et al.* of INS, Japan. Elsewhere on the experimental floor, the LBL-GSI collaboration performed a Nb + Nb excitation function experiment using the Plastic Ball detector; it was the earliest of the new series of heavy-ion experiments made possible by the uranium improvement project.

Table 5. Summary of Bevalac Complex operations during FY 1982.

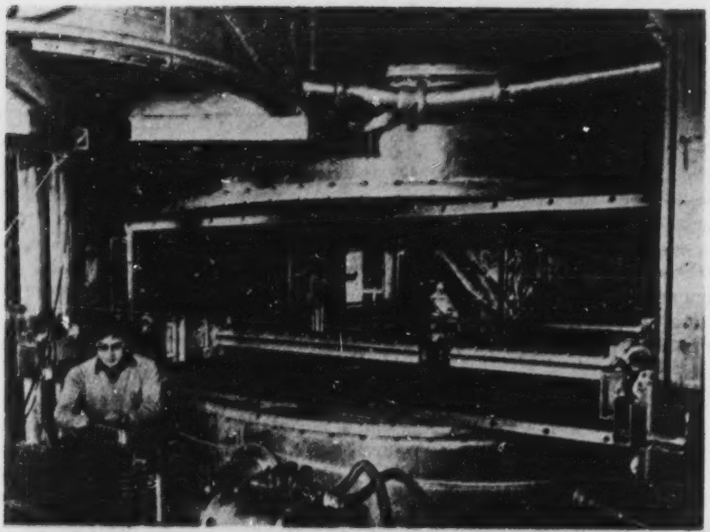
Machine Operation (hours)	
Research	1886
Tuning	930
Machine Studies	199
Unscheduled Maintenance	521
Scheduled Shutdowns	5224
Total	**8760**

Experiment Summary And Projections

	FY 1982	FY 1983	FY 1984	FY 1985
Beam Utilization for Research (hours)				
Nuclear Science	1220	1970	2880	3200
Biology and Medicine	666	980	1440	1600
Subtotal	1886	2950[a]	4320[b]	4800[b]
SuperHILAC	2151	2000	2000	2000
Total	**4037**	**4950**	**6320**	**6800**
Number of Bevalac nuclear science and SuperHILAC experiments receiving beam	**44**	**48**	**54**	**58**
Number of participating scientists	**156**	**175**	**185**	**195**
Institutions represented				
Universities	20	20	20	22
DOE National Laboratories	4	4	4	4
Other	9	10	11	12
Total	**33**	**34**	**35**	**38**
Percentage of Beam Time				
In-house staff	50.5	50	50	50
Universities	39.1	35	35	35
DOE National Laboratories	0.4	5	5	5
Other Institutions	10.0	10	10	10

[a] Multiplicity for FY 1983 estimated to be 1.13.

[b] Multiplicity for FY 1984 and FY 1985 estimated to be 1.2.



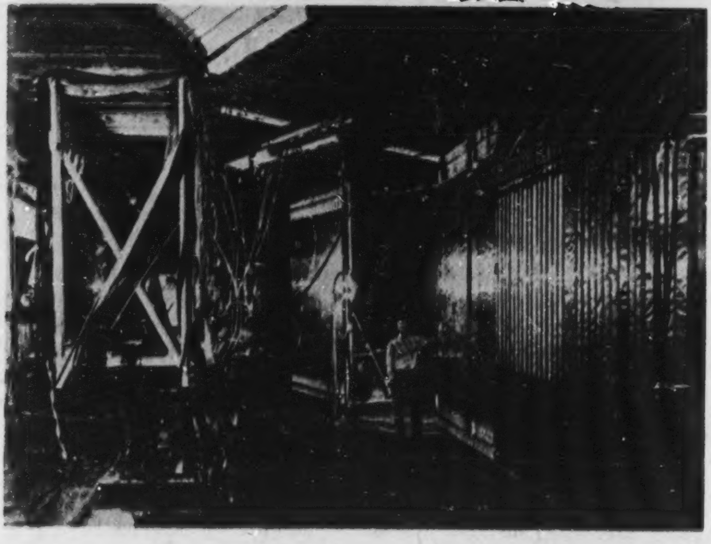


Figure 2. Two views of the Heavy Ion Spectrometer System (HISS) at the Bevalac. Top: A view looking downstream through the dipole magnet gap. Bottom: A view of the downstream detector area, showing the large-area scintillation hodoscopes. (Top: CBB 820-10981; Bottom: CBB 820-10979)

MACHINE RESEARCH AND DEVELOPMENT

With completion of the uranium beams project early in 1982, subsequent work has been aimed at performance improvements. Measurements were made of beam quality in the ABEL pre-injector system. Performance of the ion source for the heaviest ions was found to be satisfactory—typically an intensity greater than 1 pmA was obtained. Some transmission losses were found in the 750-keV column, resulting in intensities of 0.6 pmA of U in the transport line to the Wideröe. Beam emittance was found to be 0.5 π mm-mrad (normalized), which is within the acceptance of the transport line. Studies of beam transmission in the ABEL injector line pointed out problems with the beam optics. These have now been corrected (February, 1983) by relocating the Fomblin vapor stripper and providing additional quadrupole focusing between the Wideröe exit and the vapor stripper.

An increase in uranium beam delivered by the Bevalac from 2×10^4 to 1×10^6 ions per pulse resulted from these modifications. Moreover, the intensity increase in many cases should be sufficient to eliminate the need for a "tracer beam" tuning technique, which involves the use of a lighter ion beam (having higher intensity and fewer, well-separated charge states) whose charge state is chosen to give the same charge-to-mass ratio as the heavier beam. (An example is the use of $^{56}\mathrm{Fe}^{16+}$ as a tracer for $^{238}\mathrm{U}^{68+}$.) The disadvantages of the tracer technique are that it ties up two injectors at the SuperHILAC and that it is time-consuming to have to tune up the SuperHILAC to precisely match the velocities of the two beams. In the future, we anticipate more rapid and more reliable tuning of heavy beams to the Bevalac.

Work continued on development of a liquid-film stripper. The test box was modified for installation in a beam line where tests can be made using ion beams from the SuperHILAC.

To aid with tuning heavy Bevalac beams and provide data needed to optimally design future heavy-ion accelerators such as the Tevalac, we have measured the charge fractions of uranium ions at energies of 962 MeV/N and 430 MeV/N passing through various thickness targets of mylar ($Z \approx 6.6$), Cu ($Z=29$) and Ta ($Z=73$). From these we have determined the equilibrium charge-state distributions for uranium at these energies.

Uranium 68+ ions were transported in vacuum through a windowless beam line and passed through targets located upstream of the Zero Degree Spectrometer. Charge states produced by collisions in the target were spatially separated in the spectrometer and could therefore be detected by a position-sensitive ionization chamber located approximately 10 m downstream.

The observed equilibrium charge-state distributions are shown in Figure 3. Note that at 962 MeV/N the average charge state of the uranium ions increases monotonically with target Z. However, at 430 MeV/N the average charge state first rises and then falls with increasing target Z. The qualitative behavior of the charge-state distributions can be understood in terms of the different energy and target-Z dependence of the ionization cross section and the charge exchange, and radiative electron capture cross sections.

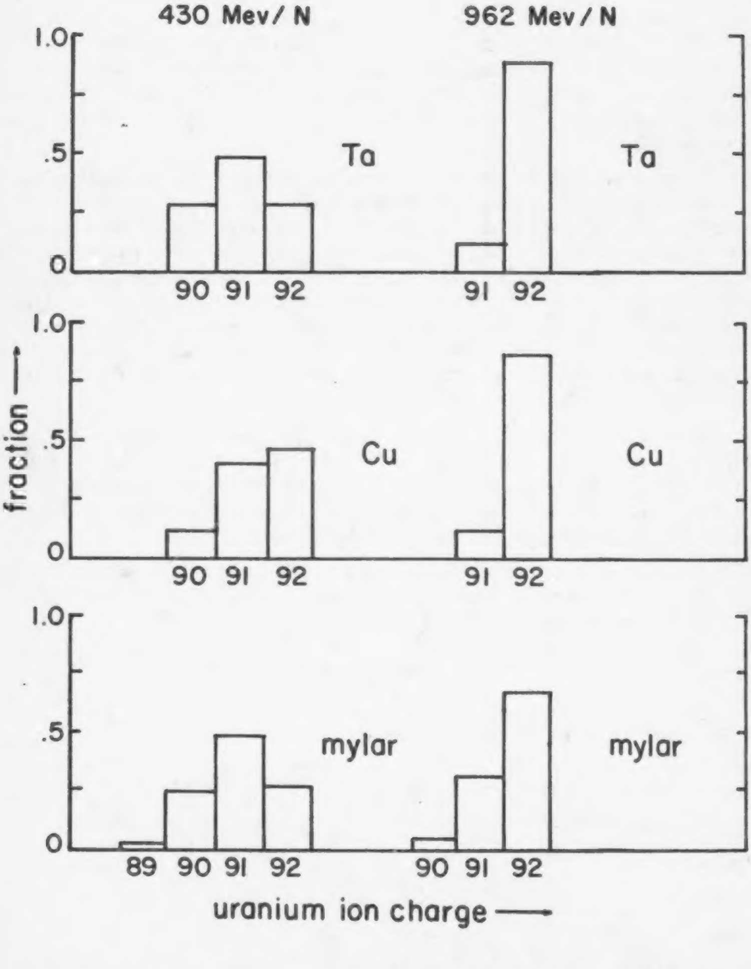


Figure 3. Equilibrium charge state distributions of 430 MeV/N and 962 MeV/N uranium from mylar (Z ≈ 6.6), copper (Z = 29) and tantalum (Z = 73) targets. (XBL 829-11834)

ACCELERATOR IMPROVEMENTS

Completion of the Bevatron local injector upgrade project, which progressed rapidly during the year, will make available a source of ions as heavy as silicon (or argon at reduced intensity) that is independent of the SuperHILAC. The programmatic goal of this effort is to enhance the efficiency of overall Bevalac operations by providing an independent injector for biomedical use. More efficient switching will then be possible between the lighter ions used for biomedical work and the heavier ions from the SuperHILAC needed for the nuclear science experimental program. This will translate directly into an increased number of beam-on-target hours for nuclear science.

The design of the upgraded injector is based on radiofrequency quadrupole (RFQ) linac technology, which has been adapted by LBL staff to the acceleration of heavy ions. In 1982 the engineering design of a working heavy-ion RFQ was completed, and a full-scale structure was built as described below. Several technical innovations (for which patents have been awarded) have been incorporated into the LBL RFQ design. Advanced mechanical design concepts were developed to permit the extremely precise alignment and verification of pole tip geometry required for optimized heavy-ion RFQ linacs. A field-stabilization technique, pioneered in a parallel R&D effort, has also been incorporated into the design. Finally, techniques for matching beam dynamics and RF parameters between the RFQ and the linac that it injects have been developed and implemented.

The configuration of the local injector before and after the upgrade is depicted schematically in Figure 4. The main elements of the project are a duoplasmatron and a PIG ion source, a two meter length of ion optics for mass analysis and matching, the heavy-ion RFQ, a new 2-βλ Alvarez linac (Table 6), a new stripper assembly, and a control system to permit rapid switching of the injector between the two ion sources.

The heavy-ion RFQ linac is designed to accelerate ions with charge-to-mass ratios as low as 0.14 from an energy of 8.4 to 200 keV/N with high capture efficiency and high overall transmission. The design parameters of the RFQ are summarized in Table 7. Beam dynamics calculations, which provide the specifications for the complex pole tip geometry, and the numerically controlled machining of these pole tips were done at LBL.

Table 6. Parameters of the new Alvarez linac.

Design frequency, MHz	199.3
Injection energy, keV/N	200
Output energy, keV/N	817
q/A	0.143
Mode	2 βλ
Stable phase	-30 degrees
Focusing sequence	+ + − −
Average axial field, MV/m	2.25-2.63
Number of drift tubes	37 plus 2 half drift tubes
Overall length, m	3.54

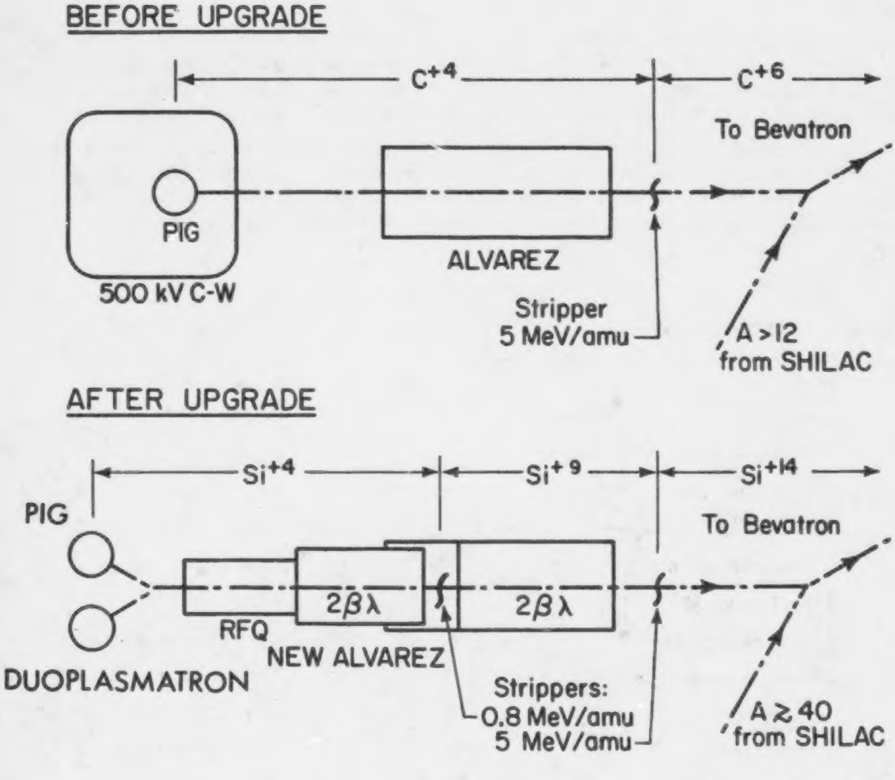

BEFORE UPGRADE
C^{+4}
C^{+6}
To Bevatron
PIG
ALVAREZ
500 kV C-W
Stripper
5 MeV/amu
A >12
from SHILAC
AFTER UPGRADE
Si^{+4}
Si^{+9}
Si^{+14}
PIG
To Bevatron
$2\beta\lambda$
$2\beta\lambda$
RFQ
NEW ALVAREZ
DUOPLASMATRON
Strippers:
0.8 MeV/amu
5 MeV/amu
A ≳ 40
from SHILAC

Figure 4. Configuration of the Bevatron local injector before and after upgrade. (XBL 8211-1308)

Much of the year's activities centered on translating these specifications into a working device. The rough cut of the vane modulations removed nominally 0.7 mm from the vane blank at cuts spaced longitudinally by 1 mm. The final machining operation, removing an additional 0.25 mm every 0.5 mm longitudinally, was done by passing the tool over the work always in one direction to prevent machine hysteresis and to remove position error in the feedback system due to finite velocity of the machine bed. The finish cut on each 225-cm vane tip required a total of 30 hr of machining time, including initial setup and tool changes. Once started, the machining continued nonstop until the vane was completed. The data for each pair of vanes are contained on 25 500-ft reels of punched mylar tape, or about 1.5 million characters of information. There were no errors detected in the large amount of data transferred.

The vane tip machining was completed in October 1982, and a surface roughness of approximately 1.6 μm was achieved. The cavity and vanes were copper plated to a thickness of 50 μm using an acid process except in the area of the vane tips. There, the 5 μm cyanide copper strike, which underlies the 50-μm plate, was the only finish given to the surface.

Figure 5 shows a typical cross section of the RFQ. Each vane is mounted using six cylindrical plugs equally spaced along the length of the cavity. These plugs fit into bored holes in the base of the vanes and are aligned against precision ground flats on the outside of the cavity. This design provides for axial, radial and transverse degrees of freedom for precise

Table 7. RFQ design parameters.

Structure	4 vane loop driven
Design ion	$^{28}Si^{+4}$
Frequency, MHz	199.3
Vane length, cm	224.86
Average bore radius, cm	0.254
Cavity radius, cm	15.583
Input energy, keV/N	8.4
Output energy, keV/N	200
Total number of cells	346
Radial matcher	6.4 cm (20 cells)
Exit matcher	54 cm (45 cells)
Normalized acceptance, π cm-mrad	0.05
Transmission	90%
Rf power, kW peak	180
Stored energy, J	0.6
Duty factor	0.002
Vane-vane voltage, kV	51
Maximum surface field, MV/m	27

vane alignment. Fiducial notches are located on each side of the vanes to facilitate accurate positioning of the vane tips. A numerically controlled mill was used to machine these fiducials during the same setup used to produce the modulated surface on the vane tips. Bars are mounted at the base of each vane for coarse frequency tuning. Provision has been made to install as many as five sets of vane coupling rings along the length of the RFQ. These aid in field stabilization of the structure and in suppressing unwanted dipole modes. One rf drive loop and one frequency tuner loop are located in opposing quadrants at the longitudinal center of the cavity. The frequency tuner penetrates the vacuum through a ferrofluidic seal and is driven with a dc gear motor. Ports for rf monitoring loops are located at six places along each quadrant.

Each quadrant of the RFQ is pumped through a radial port using a 1,000 liter/s cryogenic pump. A base pressure below 4×10^{-7} Torr in the cavity has been achieved. Electrical properties of the cavity have been studied using both low and high levels of rf power. An azimuthal field distribution balance of ±2% was achieved using 3 pairs of vane coupling rings. Axial field distribution was controlled by various end-tuner adjustments. Voltage flatness along the vanes is approximately ±5%. Figure 6 is a photograph of the assembled RFQ taken shortly before high-voltage testing began at the Bevatron.

As of this writing, the RFQ has now been assembled, tuned and recently operated at full rf power. Early tests indicate that the structure's stability, dimensional accuracy and adjustability meet the requirements that are critical for successful beam acceleration and transmission. On June 7, 1983, the first beam, N^{3+}, was accelerated in the RFQ.

Fabrication of components for the Alvarez linac is in progress, aimed toward final testing and commissioning of the upgraded local injector in early 1984. A prestripper tank approximately 3.5-m long and containing 37 drift tubes is used to accelerate the beam from 200 to 817 keV/N. Pulsed, wire-wound drift tube quadrupole magnets will provide the needed focusing gradients.

184-INCH SYNCHROCYCLOTRON

The 184-Inch Synchrocyclotron continued to operate this year as a dedicated medical accelerator, providing helium ions for radiotherapy and associated biological experiments. One hundred eight patients received 1409 treatments as part of the program to compare helium and heavier ions with the best conventional radiotherapy. Tumors treated were located in the eye, head and neck, and the torso, with emphasis on sites near sensitive structures such as the optic nerve or the spinal cord. Eleven patients having arterio-venous malformation in the central part of the brain were treated. The helium ions are stopped in a well-defined volume of a few cubic centimeters to minimize damage to nearby normal tissue.

The reliability of the cyclotron has continued to be exceptional. The time that the accelerator was unable to be used due to malfunction was less than 2% of the scheduled operating time.

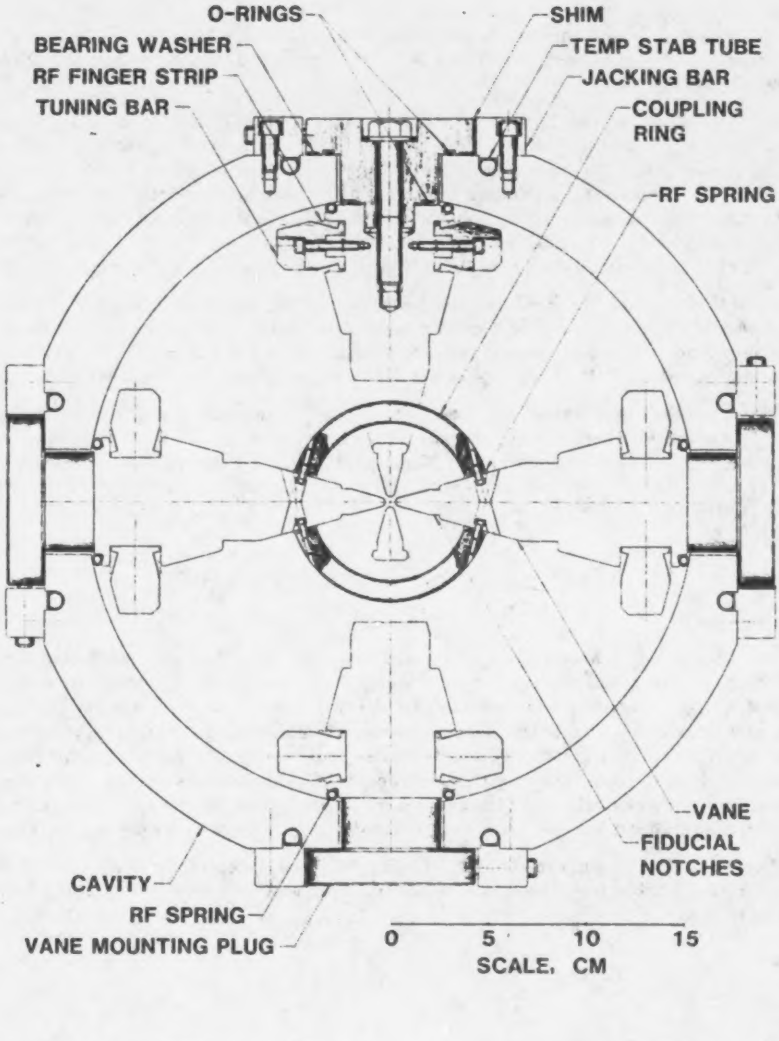

O-RINGS
SHIM
BEARING WASHER
TEMP STAB TUBE
RF FINGER STRIP
JACKING BAR
TUNING BAR
COUPLING RING
RF SPRING
VANE
FIDUCIAL NOTCHES
CAVITY
RF SPRING
VANE MOUNTING PLUG
0
5
10
15
SCALE, CM

Figure 5. Typical RFQ cross section. **(XBB 833-2642)**

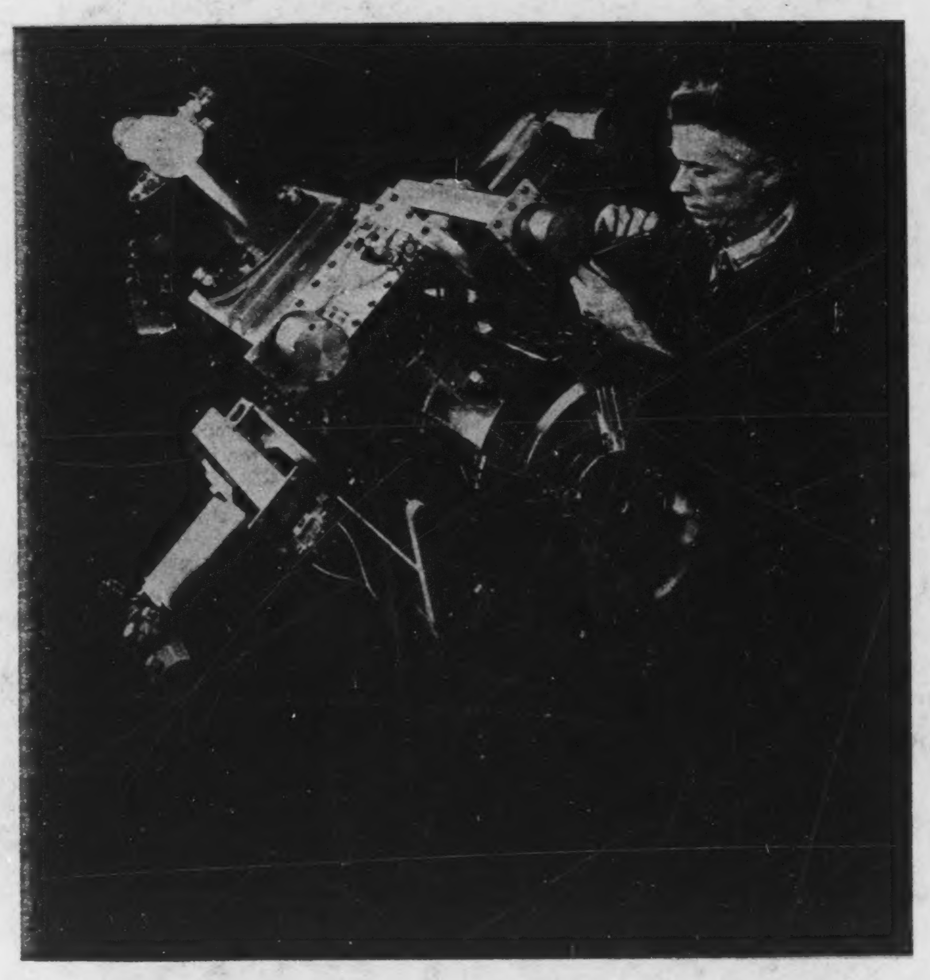


Figure 6. Photograph of the RFQ after assembly and alignment was completed at the Bevatron. (CBB 833-2193)

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LBL-15207

Nuclear Science Division

Annual Report for the Period
July 1, 1981 – September 30, 1982

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Introduction

This report summarizes the scientific research carried out within the Nuclear Science Division between July 1, 1981, and September 30, 1982. Heavy-ion investigations continue to dominate the experimental and theoretical research efforts. Complementary programs in light-ion nuclear science, in nuclear data evaluation, and in the development of advanced instrumentation are also carried out.

We began this period looking back upon past achievements as LBL celebrated its 50th anniversary. The real value of these remembrances was to draw our attention to the exciting possibilities of the next 50 years. Of particular significance, the dedication of the (new) third injector at the SuperHILAC was a prelude to the new generation of relativistic heavy-ion physics that began in early 1982 with the *successful acceleration of* ^{238}U *ions at the Bevalac.*

Results from Bevalac experiments employing a wide variety of heavy ion beams, along with new or upgraded detector facilities (HISS, the Plastic Ball, and the streamer chamber) are contained in this report. These relativistic experiments have shed important light on the degree of equilibration for central collisions, the time evolution of a nuclear collision, the nuclear density and compressional energy of these collisions, and strange particle production. This work receives continuing guidance from close interactions with the nuclear theory group. The phenomenon of short mean free paths of projectile fragments remains the greatest mystery in Bevalac research. Collaborative "anomalon" emulsion efforts and a new electronic detector being constructed to simulate directly the visual detectors are described in this report.

Reaction mechanism work dominates the heavy-ion research at the 88-Inch Cyclotron and the SuperHILAC. Recent experiments have contributed to our understanding of the nature of light-particle emission in deep-inelastic collisions, of peripheral reactions, incomplete fusion, fission, and evaporation. Nuclear structure investigations at these accelerators continue to be directed toward the understanding of the behavior of nuclei at high angular momentum. Research in the area of exotic nuclei has led to the observation at the 88-Inch Cyclotron of the β-delayed proton decay of odd-odd $T_z = -2$ nuclides; β-delayed proton emitters in the rare earth region are being investigated at the SuperHILAC.

At all three accelerators the trend is toward more complex detectors measuring more and more parameters per event. To attack the reduction and analysis of such large quantities of data, the Division has pioneered a unique parallel-processing computing architecture. The successful operation of the Modular Interactive Data Analysis System (MIDAS) prototype during this period demonstrates the principles of this design; subsequent development has provided computational power for data analysis equal to that of a CDC7600.

All three accelerators support strong outside user programs, including both domestic and foreign cooperative efforts. In particular, major collaborations with our German and Japanese colleagues continue to flourish.

Division members published 184 reports and journal articles including 11 Ph.D. theses. Affiliated with the NSD during this period were 5 faculty senior scientists, 18 staff senior scientists, 31 staff scientists, 1 divisional fellow, 20 postdoctoral fellows, 24 graduate students, and 42 technical, administrative, and clerical support staff. Our research continues to thrive from a productive relationship with the UC campus, from the diversity of ideas and talents contributed by our many visiting scientists (~115), and by the cross fertilization from other LBL divisions. Honors accorded to Division members include Luciano Moretto's Alexander von Humboldt Award and Michael Perry's Achievement Reward for College Scientists (ARCS) Foundation Award.

The fall meeting of the APS Division of Nuclear Physics at Asilomar (October, 1981) was organized by NSD staff members. Five workshops, focusing on topics from nuclear structure data evaluation and nuclear dynamics to anomalons and cosmic-ray emulsion experiments and future planning for heavy-ion experimental needs, were also organized by Division scientists.

The Division is actively engaged in looking to meet very high energy heavy-ion physics needs beyond the 1980s. Over 100 physicists from throughout the world met at LBL in September, 1982 (VENUS-82 Workshop) to review the physics objectives and capabilities of a dedicated heavy-ion accelerator complex providing at least 10 GeV/N beams over the entire range of the periodic table for fixed target experiments. This Workshop was a prelude to the Tevalac R & D proposal submitted to DOE in December 1982. Several new detector and accelerator improvements are underway, directed toward investigation of the many exciting avenues yet to be explored.

Joseph Cerny

Bevalac Research Program

H.G. Pugh

The Bevalac is operated by LBL's Accelerator and Fusion Research Division and has the unique capability world-wide to collide heavy and very heavy nuclei against each other at sufficiently high energies that the internal structure of the composing nucleons is changed. The new ideas of nuclear physics which emerge from relativistic field theories devised to describe such collisions are in many instances strikingly different from our preconceptions of nuclear behavior. New configurations of nuclear particles are found to be possibly stable and in the extreme limit it is found that the entire system of colliding nuclei may be converted into a new state of matter called the quark-gluon plasma. Such ideas cannot be investigated with conventional probes such as electrons or protons since they involve raising large volumes of nuclear matter to conditions of high density and pressure such as can only be brought about when very large projectiles, i.e., nuclei themselves, are used. The Bevalac program consists of a systematic study of the behavior of nuclei under these conditions, with hot pursuit of any unusual phenomena that seem to be encountered.

The Bevalac provides beams of ions up to uranium at energies from 50 MeV/ nucleon to 2.1 GeV/nucleon (1.0 GeV/nucleon for uranium). To use these beams a large number of user groups converge on LBL from all parts of the United States. An international contingent is led by major groups from GSI, Darmstadt, W. Germany, and INS, Tokyo, Japan, which make a leading contribution to the research program, as well as the many smaller groups engaged, for example, in emulsion experiments.

Experiments are selected by the Bevalac Nuclear Science Program Advisory Committee, which meets twice a year. The present members are Professor Herman Feshbach, MIT, Chairman; Professor Robert Klapisch, CERN, Geneva, Switzerland; Professor David K. Scott, Michigan State University; Professor Erich Vogt, University of British Columbia, Canada; Dr. William A. Wenzel, Lawrence Berkeley Laboratory; and Professor Toshi Yamazaki, University of Tokyo, Japan. Within the extremely limited beam time available, collaborations typically receive 100 hours per year. Under these circumstances there is strong emphasis on complex, flexible, and efficient detectors and data acquisition methods, or else on experiments of a decisive quality.

The Bevalac Users' Association meets annually, and its Executive Committee holds telephone conference calls with Laboratory management to discuss current problems. During FY83 the charter of the Association is being revised to give the outside users an enhanced role in the Laboratory's activities. Users' workshops in specialized areas of research serve to coordinate activity. In the past year a JACEE workshop was held in August 1982 to study the state of the art in the study of nucleus-nucleus collisions with cosmic rays, and a Tevalac workshop was held in September 1982 to develop plans for a new accelerator. The Dilepton Workshops have continued on a more informal and more frequent basis and a Dilepton Spectrometer (DLS) project has been developed. In June 1983, the 6th High Energy Heavy Ion Study will be held, in conjunction with the second Anomalon Workshop. This event is expected to attract a large number of visitors from many parts of the world.

The phenomenon of short mean free paths of projectile fragments has continued to be the greatest mystery in Bevalac research. Since the first Anomalon Workshop in February 1982, many additional workers have entered the field and much improved statistics using visual detectors are anticipated. There have been several attempts in the past year to study the short mean free path particles (or "anomalons") by electronic techniques. Searches have been made for photons emitted downstream from a production target and for sharp photon lines in the spectra emitted from the target fragmentation region, both in the inclusive spectra and in the effective mass spectra of photons in coincidence with deuterons and tritons. Neither of these experiments found an anomalon signal, ruling out certain hypotheses concerning their nature. Several theoretical groups have reanalyzed the emulsion data to seek explanations. It has been suggested that the effect could be explained by molecular nuclei with unusually long lifetimes or that the cross sections observed for anomalons as a function of Z correspond almost exactly to the limit which a nuclear cross section could have, i.e., the sum of the nucleon-nucleon cross sections. A third paper suggests that a relativistic mean field theory consistent with all known facts about nuclear physics would permit nuclei in certain excited states to have extra-long range forces. An important experiment has been conducted using the Plastic Wall to distinguish between the two hypotheses concerning anomalons, i.e., that they correspond to 6% of nuclear fragments having a 10 times increased cross section or, alternatively, 100% of nuclear fragments having a 20% increased cross section coupled with a 10^{-11} second lifetime. These can be distinguished by comparison of dense and dilute targets. Preliminary results favor the former hypothesis. A new electronic detector is being constructed to directly simulate the visual detectors. Using the ring-imaging Cerenkov technique, it is hoped that the detector will give direct results on the anomalons, and be usable as a trigger for other more sophisticated detectors such as HISS.

Recent work has shed important light on the progress of relativistic heavy ion reactions. These experiments have investigated the degree of equilibration for central collisions, the time evolution of a nuclear collision, the nuclear density and compressional energy of these collisions and strange particle production.

In 1982 ions up to uranium became available and preliminary experiments were carried out with each of the new beams as they were developed.

- The first of the new beams, krypton, was used in early 1982 to test the streamer chamber for high multiplicity events and to indicate several improvements necessary, which are now being implemented.
- Measurements of the range-energy relationship for uranium ions in emulsion showed that the higher-order corrections in the infra-red region of QED cancel each other. The range of 1 GeV/nucleon uranium ions in emulsion is only 4 cm!
- Characteristic event types for uranium interactions in emulsion have been identified, including binary and ternary fission, grazing and head-on collisions.
- Fission cross sections have been studied as a function of beam energy using solid state detector techniques.
- The equilibrium charge state distribution for uranium ions passing through various materials has been studied. It is found that 90% of uranium ions at 1 GeV/nucleon can be reduced to the fully stripped state. This is the first time that bare uranium nuclei have ever been produced in the laboratory.
- Atomic physics measurements have been carried out on xenon ions, in particular of X-ray yields when they pass through various materials.
- Inclusive charged particle spectra have been measured for La+La collisions at 800 MeV/nucleon.
- Exclusive 4π geometry measurements have been made for 800 MeV/nucleon Nb+Nb collisions with the Plastic Ball-Wall. Evidence for equilibration was obtained.
- Gold beams were used in experiments to calibrate cosmic-ray detectors.

In experiments to be carried out in the near future, pion multiplicities will be studied for Nb+Nb in the streamer chamber. A search will be made for effects due to the pion condensate in La+La, the Plastic Ball experiments will be extended to Au+Au, and measurements will begin towards studying the Lamb shift in hydrogen-like uranium (U^{91+}).

Finally, in order to acquire the most coherent and useful set of data, we have chosen to study whenever possible a set of monoisotopic nuclei. Thus Nb, La and Au feature strongly among the early experiments.

New Detectors

The Plastic Ball-Wall is complete, has taken data, and the first results, on coalescence phenomena, have been submitted for publication. Gas detectors are being added inside the scatter chamber to provide data on very heavy fragments.

The streamer chamber has undergone a fairly extensive upgrade, especially with the addition of a 400-element hodoscope to provide end-point and particle identification measurements in the forward direction. A further improvement is the installation of an ultra-violet laser to produce artificial tracks which are recorded by a CCD camera and used to monitor chamber efficiency and stability. Use of the complete system will begin in summer 1983 and a series of approved experiments will continue through 1984.

HISS has operated successfully with the prototype detectors, but data taking was severely handicapped by the restriction of the Bevalac to half field during FY82 (with the exception of one weekend, not allocated to HISS). Analysis of data on carbon fragmentation has proved very interesting, with an unexpectedly large proportion of very high nuclear excitation. Confirmation of these results with better statistics is a high priority in FY83. The Phase II detectors will be completed in FY84. Tests on the MUSIC box indicated that it will reach its design goals of distinguishing one unit of charge at charge 92, but improvements still remain to be carried out on the gas handling system and electronics. of value.

The past year has seen major development in our plans for the Dilepton Spectrometer (DLS). A pilot experiment to look for single lepton production has been approved by the Program Advisory Committee, and a large collaboration of outside users is preparing the final plan for the dilepton spectrometer. The CERN Lampshade Magnet and detectors have been inspected as a basis for the Bevalac experiment and a final choice of procedure will be made by June 1983. This experiment promises to give extremely important information of the internal state of interacting relativistic nuclei. Whether dileptons are observed or not, the measurement will be a crucial test of high temperatures reached. If enough dileptons are observed to make studies possible as a function of effective photon mass and of projectile and target masses and beam energy, the spectrometer will surpass other methods of studying hot nuclei.

In accordance with our interest in pursuing studies to their logical conclusion, LBL is continuing involvement in the α-α experiments at the CERN ISR. Since that facility will be closed in FY84, continued development requires the CERN PS and SPS. An approved LBL/GSI/Heidelberg/Marburg/Warsaw collaboration will initiate these studies, by providing an ^{16}O ion source using an RFQ pre-injector. The initial experiment, to be carried out in FY85-86, will use 6–13 GeV/ nucleon ^{16}O beams from the PS, and will consist of target fragmentation studies with the Plastic Ball, studies of the participant region and particle production with a new streamer chamber to be provided by GSI, and studies of anomalous projectile fragments using emulsions. It is expected that the program will continue in FY86-87 with ^{16}O beams from the SPS at energies up to 200 GeV/nucleon. These experiments will be the first test of nuclear stopping power in this energy region and the overall program will map out the possibilities for creating regions of high density in heavy ion collisions. In accord with our present knowledge, the Tevalac project addresses the beam energy region where high baryon densities can be produced. Our work developing that project and the CERN experimentation will continue hand-in-hand.

SuperHILAC Research Program

R.M. Diamond

The SuperHILAC is the only accelerator in the United States capable of accelerating very heavy ions far enough beyond the Coulomb barrier to permit studies of compound-nuclear and deep-inelastic reactions. In recent experiments the new injector, ABEL, has reached its design characteristics, producing beams of ~1 (charge) microampere of 8.5 MeV/nucleon ^{197}Au and ^{238}U. Thus the SuperHILAC now furnishes ions with energies from 1.2-8.5 MeV/nucleon of ^{40}Ar to ^{238}U with intensities of several (charge) microamperes to one (charge) microampere, respectively. It is a National Facility open to all qualified research groups in the United States and Canada and to collaborating groups in Europe and Asia. The use of two injectors in time-shared mode means that in normal operation the SuperHILAC provides up to three different beams to users: a very heavy-ion beam at 32 pulses/s for the principal user; a different beam at 2 pulses/s for injection into the Bevatron; and either one of these beams, at a different energy if necessary, for a parasite user at the SuperHILAC to test equipment or even do a low duty-cycle experiment. Due to increased power costs during the past year, the total number of hours available to experimenters, 2151, is slightly reduced over the previous year, and again is about 3/4 of the total scheduled time. Beams used included ^{48}Ca, ^{56}Fe, Kr, Xe, ^{165}Ho, ^{139}La, ^{197}Au, ^{208}Pb, and ^{238}U.

A program advisory committee currently composed of Dr. Peter Bond (Brookhaven National Laboratory), Chairman, Dr. C. Lewis Cocke (Kansas State University), Prof. David B. Fossan (State University of New York at Stony Brook), Prof. C. Konrad Gelbke (Michigan State University), and Dr. Jørgen Randrup (LBL) meets twice a year to select the best experiments to be carried out. In 1983, Drs. Cocke and Bond will be replaced by Dr. John Hardy (Chalk River Nuclear Laboratory) and Dr. Shelton Datz (Oak Ridge National Laboratory), and Prof. Fossan will serve as chairman. They work from written proposals submitted by about two dozen research groups. Last year approximately 52% of the time went to outside groups and 48% to groups within LBL. The experimental work performed last year can be divided into four main categories: heavy-ion reaction studies (~1/2); nuclear structure studies (~1/6); exotic nuclei (~1/6); and atomic physics (~1/6).

Thus, reaction mechanism work, particularly studies of deep-inelastic reactions, dominates the research program. Major problems involve the transfer and alignment of angular momentum in the product fragments, the energy and angular distributions of light particles emitted and what they tell about the emitting system (whether it is the combined di-nucleus or the resulting fragments after separation, whether evaporative particles or pre-equilibrium ones are involved, and what is the role of composite particles such as Li and Be nuclei). For example, from the (low) temperatures deduced from the spectral shapes of the α-particles emitted and the kinematics of the fragments, it has been inferred that energy thermalization and particle evaporation are even faster than "fast" fission. Studies of heavy-ion fusion reactions are also being done, for example, the variation of the cross section with bombarding energy for heavy projectiles and targets. The experimental results cannot be represented by simple one-dimensional models even allowing for frictional effects. But the inclusion of a neck degree of freedom for the di-nuclear complex gives better agreement; such a model (by Swiatecki) leads to two types of saddle points and requires an extra (energy) push to get the two nuclei to fuse. Tests of this idea are in progress. It should be mentioned that in a number of the reaction mechanism studies performed it was found useful to carry out the inverse reaction, that is, to use the smaller nucleus as the target and bombard it with the larger one, e.g., ^{165}Ho on ^{56}Fe, rather than ^{56}Fe on ^{165}Ho. The advantages are that the resulting products have larger velocities and so are easier to get through window foils on gas counters and ionization chambers, and the products are focused in a smaller solid angle.

The nuclear structure studies mainly make use of the high-Z projectiles available at the SuperHILAC (Xe and Pb) to multiply Coulomb-excite target nuclei, or use inverse reactions to obtain large recoil velocities in order to measure lifetimes by Doppler-shift techniques or to measure g-factors of short-lived states of high spin by means of the enormous transient magnetic fields acting on fast-moving ions in ferromagnetic materials. An example of the last type of problem is furnished by an LBL-Chalk River collaborative work which yielded the surprising result that the transient field in cooled ferromagnetic gadolinium did not continue to increase with increasing ion velocity as most people had expected, but reached a maximum at a velocity of about 5% c. Now, having calibrated this field as a function of ion velocity, the technique will be used to measure the g-factors of high-spin states, and hopefully, even the average of regions of continuum states.

The third type of research category is the study of exotic nuclei. A major attempt to produce nuclei of a superheavy element by means of an extended ^{48}Ca bombardment of ^{248}Cm was carried out at the end of 1982 by a collaboration of LBL and GSI scientists. No superheavy element events were observed, and the upper limits on the cross sections are currently being refined. The use of a gas-filled magnetic separator SASSY allowed observation into the millisecond region, and the cross section limit for production of superheavy nuclei in this time range is on the 100 picobarn level. The heavy element chemistry groups looked for half-lives in the range of hours to a year and have set cross-section limits of the order of some tens of picobarns. The next major effort on superheavy elements is a repeat of the ^{48}Ca+^{248}Cm bombardment, but done at GSI in March, 1983, again as a collaboration of LBL and GSI nuclear physics and chemistry groups. In the future, the LBL groups may try to make an isotope of element 108 by a ^{48}Ca bombardment of ^{226}Ra in the hope that it might be as long-lived as microseconds. In addition to these studies, the on-line isotope separator OASIS is in operation and the transport system from the separator to the spectroscopy laboratory above it is now finished. OASIS has been used to characterize five new beta-delayed proton emitters and to hunt (so far unsuccessully) for new ground-state proton emitters. This instrument can now separate about 70% of all the elements, and will be used for isotope studies going out towards both the neutron and proton drip lines.

The final category of research programs is heavy-ion atomic physics. One major class of studies here has to do with the fine structure in the spectra of one-and two-electron ions in order to make rigorous tests of quantum electrodynamics and of relativistic corrections. A number of tests with hydrogen-like ions have been performed, and now new calculations for the two-electron ions will permit even more precise comparisons with experimental studies being done, or planned, with He-like ions of Ar, and possibly up to Kr. To produce these ions at very low velocities so that Doppler shifts are negligibly small, the appropriate gas is bombarded with U ions of 4–5 MeV/nucleon which ionize the gas atoms, but impart recoil velocities corresponding to only a few electron volts. Other studies are measuring the electron-capture cross section at very low velocities. Still another program is attempting to measure correlated electron capture and K-shell excitation by highly stripped, heavy ions (e.g., Li-like ^{40}Ar) incident on gas targets (this is like an inverse Auger transition). It has been suggested that a similar process is an important energy-loss mechanism in high-temperature fusion plasmas, but such experiments have only recently been performed in the laboratory, in preliminary runs at TUNL, Brookhaven, and LBL. Another program involves the measurement of K-shell ionization probabilities in the collision of high-Z ions as a function of nuclear excitation energy (where the latter reflects the length of the reaction or sticking time). Unfortunately, the initial results with Xe on Pb and Th targets are very much complicated by the large number of internal conversion K x-rays. But since the internal conversion yield appears to remain approximately constant with an increase in the combined Z of the di-nuclear complex, while the K-vacancy production goes up strongly, the answer is to go to Pb-Pb and U-U collisions. Successful experiments would provide an atomic clock for these deep-inelastic reaction times. Other programs deal with beam- foil studies of the energies and lifetimes of transitions in highly stripped Ne-like ions of Xe and Ho. Relativistic corrections to the calculated energies are greater than 100%, and there are much larger effects on the lifetimes of certain types of transitions. The measurements are of direct interest to studies of high-temperature and high-density plasmas, and to schemes for producing x-ray lasers in high-Z Ne-like systems.

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BIOLOGY AND MEDICINE DIVISION
ANNUAL REPORT 1981-1982

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4. RADIATION BIOPHYSICS

INTRODUCTION

C. A. Tobias

The expertise of the Radiation Biophysics Group is centered in basic biophysics and cellular radiobiology. Research in these fields has resulted in novel approaches to cancer diagnosis and therapy. An interdisciplinary team is carrying out systematic studies with the aim to improve the control of cancer, and this progress report contains an evaluation by J. Fabrikant of the current status of our diagnostic program and a progress report on the therapeutic investigations by J. Castro and his group. The advances made in computerized therapy planning are described by G. Chen.

The Bevalac accelerator is the center of many of our research activities. Because it is a unique source of heavy particles, our group is involved in international collaboration at various levels. There is particularly strong interaction with Canadian, German, and Japanese laboratories, and in each of these countries there is a strong interest in building heavy ion accelerators for biomedical research. After an improvement program was finished in June 1982, a beam of the heavy element uranium was obtained at the Bevalac, and it is now feasible to accelerate any of the nuclei in the periodic table. Most of the biomedical interest centers on the lighter ions, up to atomic number 26 (iron). Iron nuclei are important components of space radiation and pose a potential health hazard on extended space flights. Even heavier nuclei can occur in space radiation, and there are long term plans to explore the mechanism of action of the very heavy nuclei on living cells and tissues.

Studies of the effects of various heavy ions on mammalian cells in culture have pointed to particles with atomic numbers 13 to 20 as candidates for statistically controlled therapeutic trials. Whereas light nuclear beams such as protons and helium ions are useful in cancer therapy because of their good depth-dose distribution, the heavier particles also have a significant effect in depressing the radiobiological oxygen effect, altering and reducing the magnitude of enzymatic repair of injury caused by these particles, and reducing the variation of radiosensitivity of cells in various phases of the cell division cycle. In preparation for more extensive medical studies, in late 1982 three patients were treated for the first time with therapeutic schedules of 700 MeV/nucleon silicon beams.

The medical studies are supported by an extensive effort to measure early and late effects produced by various particles in normal and tumor tissues. One of our goals is to quantitatively understand the mechanism whereby these particles cause biological effects. Radiation biology of low LET radiations, such as x and gamma rays, is found in the idea that there is a quantitative dose-effect relationship for the energy transferred to tissue. The dose concept is important to heavy ion effects also; however, it appears that the microscopic structure of ionizing particle tracks plays an essential role in determining the nature and quantity of lesions produced in the genetic material DNA.

When heavy ions hit the atomic nuclei of tissue fragmentation may occur. A single beam particle may thus produce two or more nuclear fragments. Each of these fragments produces ionization and the joint effect is responsible for producing the biological lesions. The effect of each fragment depends on its velocity and charge. Several aspects of the fragmentation research by W. Schimmerling et al. are described in this review. Of special interest are the cross sections for proton and neutron production. Another variable is the efficiency by which the particles are able to produce ionization in gases, which determines the efficiency of dose measurement.

After the primary process of ionization and excitation of atomic processes has ended, the chemical phase of radiation effects begins. Reactive free radicals are formed in the aqueous milieu of cells, and their reaction with biological materials produce macromolecular lesions. An essential aspect of this process is the manner in which DNA injury is produced by heavy ions. This problem is discussed by A. Chatterjee.

Another study is in progress on correlating the track structure and fragmentation effects with the lethal effect produced in human cells. The successful completion of this work will allow accurate estimation of the effects of mixed heavy-ion irradiation and will become the basis for dose schedules in heavy-ion cancer therapy. E. Blakely et al. show their preliminary conclusions in this report, and Ruth Roots discusses the relationship of DNA lesions to the cellular effects. We have developed a new model for quantitating the cellular responses, the repair-misrepair model, and this model is also discussed.

The quantitative study of cellular effects is usually limited to cell isolates cultured *in vitro*, and from the results we infer the nature of injury in intact tissues. We have already completed research on the effects of various heavy ions on established cell culture lines. However, most of these cell lines represent cells of connective tissue (fibroblasts), and there is some evidence that most established cell lines may actually be "tumor cells." In culture some essential cell properties are lost and tumor cells have an advantage over normal cells because they can grow under environmental conditions where normal cells cannot grow well. Attempts are under way to culture normal human cells and to determine their response to heavy-ion radiation. One of the approaches is to prepare *de novo* cultures of human epithelial cells, freshly isolated from their donors. The laboratory has some cell isolates from both normal and cancerous human breast tissues. The normal human cells appear more sensitive to radiation than cultured human fibroblasts, and they are also more sensitive than *de novo* cultured breast cancer cells. T. Yang et al. give an account of progress in this research. In a separate study, we take stabilized cultures of normal diploid human fibroblasts (the IMR-90 strain), and compare them to a variety of human cells derived from different sources. The most sensitive cell we studied came from a patient with ataxia telangiectasia. These cells are more sensitive than our other normal and tumor cell strains. What are the factors that determine the relative sensitivity and resistance of various human cell strains? We know that there are some variations in the yield of the initial macromolecular radiolesions. During the last few years, however, it became clear that differences in the regulation and efficiency of the enzymatic repair system are important determinants of cell sensitivity. We have particular interest in the repair processes as they occur in various parts of the cell division cycle, and we study these processes in synchronized cell populations and under circumstances of controlled growth. Initial work has been completed on the modification of potentially lethal damage by inhibition of DNA polymerase enzymes that are believed to be essential for repair.

Heavy ions are more effective in producing cell transformation than low LET radiations. When viruses are used for transforming cells *in vitro,* radiation acts to enhance the process. Heavy ions are much more effective in enhancing cell transformation caused by simian virus SV40. There is a likelihood that the heavy ions produce lesions in DNA that serve as loci for the integration of viral DNA into the host, and that some of the radiation repair enzymes are also needed for cell transformations. T. Yang describes the ongoing work.

Like other ionizing radiations, heavy ions produce late effects and carcinogenesis. The magnitude of these effects must be known in order to protect astronauts from the carcinogenic and deleterious effects of space radiation. We also need quantitative information on carcinogenesis of heavy ions in order to assess potential hazards for cancer patients if they receive heavy-ion therapy. E. Alpen has a long term study in progress on the induction of cancer in endocrinologically stimulated Harderian glands of mice exposed to various heavy ions. The carcinogenic effects are greater with heavier particles, but they do not exceed the carcinogenic potency of fission neutrons. Other long term studies include cataract induction, and the long term effects of fractionated whole body exposure. These effects and the effect of heavy ions on the blood forming system of the body are studied by J. Ainsworth. Another study by A. Rodriguez attempts to bridge the gap in our knowledge between cellular and tissue effects. S. Curtis is attempting to unify the various theories concerning the biological effects of radiations with the mathematical model.

The laboratory has a protracted study in progress on the effects of external magnetic fields on the circadian rhythms of mammals. T. Tenforde reports the progress to date. In contrast to earlier reports by others, magnetic fields, even with considerable field strengths, do not appear to change the physiological rhythms of the body. They do produce measurable effects on the electrocardiogram, however, and these effects have been quantitated by C. Gaffey. Other studies with magnetic fields include an electroretinographic study of the responses of the eye to light in the presence of magnetic fields. M. Raybourn is in charge of studying ocular effects; he also has data on the effects of pulsed laser light exposures on vision.

H. Mel has developed basic biophysical methods to study the rheological properties of cell membranes exposed to deleterious environmental agents. These methods are of interest in a variety of fields.

This past year has been one of interesting research problems and some fruitful results; as a groups, we look forward to another year of study and collaboration.

Bevalac Studies

PHYSICAL CHARACTERIZATION OF ENERGETIC HEAVY-ION BEAMS

Walter Schimmerling, T.S. Subramanian,[*] W. John McDonald,[†] Selig N. Kaplan,[‡] Ahren Sadoff,[§] and George Gabor[‖]

When beams of heavy ions are used in radiation therapy and biology, the character of the beam is altered as the particles travel through tissue. The velocity of the particles is affected by electromagnetic interactions that slow and spread the beam. Fragments are produced by nuclear interactions and these are also affected by passage through subsequent material. The biological effects produced by the beam depend on the fragments present as well as their fluence, charge, and velocity. For example, the relative biological effectiveness (RBE) and oxygen enhancement ratio (OER) depend on all of these quantities.

We use the multidetector particle identification spectrometer described in earlier annual reports to identify each particle in the radiation field and to measure its velocity. With this spectrometer we have begun to study reaction cross sections, angular distributions of emitted particles, fluence spectra as a function of absorber thickness, the energy loss of relativistic heavy ions in matter, and the dependence of W, the average energy required to produce an ion-pair in an ionization chamber, on the charge and energy of the particles.

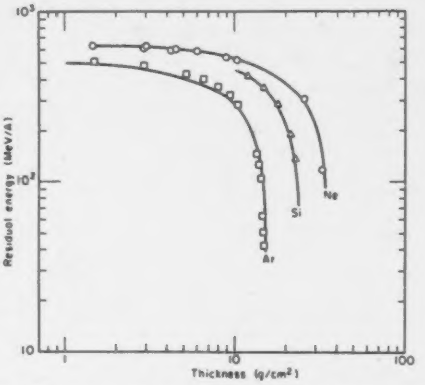

Fig. 1. Heavy ion energy per nucleon as a function of range.
(XBL 824-3782)

RANGE-ENERGY RELATION

Accurate information on the energy loss of the incident heavy-ion beams is obtained almost as a byproduct of our work, in the form of velocity (and, hence, energy per nucleon) measurements as a function of absorber thickness. The experimental points in Fig. 1 are an example of such data (uncorrected for the increase in path length due to multiple scattering of the particles and other systematic effects). From such data, the range of the incident particles can be obtained by extrapolating to zero velocity, and the experimental range-energy curve thus calculated can be compared with theoretical calculations to yield a deeper understanding of the processes responsible for the energy loss of high-energy heavy ions.

It is also useful to have available simple means to calculate the range-energy relation of high-energy heavy ions in arbitrary materials, e.g., for use in a programmable calculator or even in a computer model of the beam transport in bulk materials of arbitrary composition. A suitable approximation is based on the polynomial approximation given by Barkas and Berger[1] as a fit to their tabulated data for protons:

$$\log\lambda = \log\left(\frac{A}{Z}\right) + \sum_{n=0}^{3}\sum_{m=0}^{3} \alpha_{mn} (\log I_{adj})^m (\log\tau)^n, \tag{1}$$

where

τ = the energy of a proton in MeV,
I_{adj} = the mean adjusted ionization potential,
$\left(\frac{A}{Z}\right)$ = the average ratio of atomic weight to atomic number in the energy degrading material, and
λ = the range in g/cm^2.

Barkas and Berger obtained coefficients α_{mn} in Equation (1) that reproduced their table data with an rms percent variation of 0.6% between 7 and 1200 MeV. We have adapted Equation (1) for use with high-energy heavy ions, replacing τ, the proton energy, by ϵ, the heavy ion energy per nucleon (in MeV/A) and scaling the range obtained by a factor A/z^2 (A = number of nucleons in incident ion, z = charge of incident ion). A range extension can also be calculated to refine this approximation. Further improvements in the fit to tabulated data can be obtained by including a higher order power in the polynomial of Equation (1).

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The solid curves in Fig. 1 have been calculated following this prescription. It may be seen that the approximation is quite adequate for neon and silicon, but may not be as good for argon.

MEASUREMENTS OF W FOR HIGH-ENERGY HEAVY IONS

The linear relationship between energy deposition and ionization provides the basis for a large body of measurement results in radiation dosimetry. An accurate measurement of the constant of proportionality W (eV/ion-pair) requires precise and independent measurements, or inferences, of energy deposition and free-charge production. A comprehensive review and evaluation of W measurements may be found in ICRU-31.[2] High-energy heavy ions used in radiation therapy have a considerably different range of charge, mass, and velocity than the radiations, alphas and electrons, for which there are extensive measurements of W. Because for high-energy heavy ions, the energy transfer is small compared to the total energy, W measurements may be made at a constant velocity. Previous measurements on high-energy heavy ions are relatively sparse, were each restricted to a single nominal energy and employed integral techniques. The present work measures the ratio of energy deposited to charge collected on an event-by-event basis. For each particle traversing the system a measurement is made of particle velocity before entering the ion chamber, and of differential and total energy loss after leaving the chamber. These measurements permit, in addition to determination of energy, identification of particle mass and charge.

W values were obtained both for primary-beam ions and for some fragments produced by primary-beam nuclear interactions in the energy degrader. Figure 2 shows the measured W as a function of energy for Ne, Al, and Si in P-7 gas, where the most detailed measurements were made. The measurements covered an LET range of 20 to ~100 keV/μm. Absolute ion kinetic energy, to a precision of 2% over the range of measurement, was determined by measuring incident velocity with a time-of-flight spectrometer. Ion identification was confirmed by total and differential measurements of exit energy with a stacked Si wafer detector. Charge production was measured with a parallel-plate pulse ionization chamber, mounted perpendicular to the beam axis, and a low-noise charge-sensitive pulse amplifying system calibrated by injecting pulses of accurately know charge. Corrections for the finite pulse-shaping time and for asymmetries in charge collection were calculated using the measured response times of the electronics and published drift-velocity data. The corrections for partial collection of positive charge and for the small increase in ionization density from entrance window to exit window were ≤1%. The data were corrected for energy losses due to uncompensated delta rays leaving the thin ionization chamber.

The weighted mean and the standard deviation of the points about the mean in Fig. 2 are

$$W_{(P\text{-}7)} = 26.3 \pm 0.8 \text{ eV/ion-pair.}$$

This result is shown by the thick line and shaded area in Fig. 2. For comparison, W values for alphas and electrons in P-7 were calculated using the recommended W

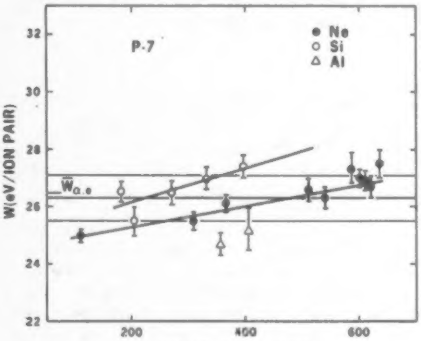

Fig. 2. Measured W-values as a function of energy for neon, silicon and aluminum in P-7 gas. *(XBL 826-10363)*

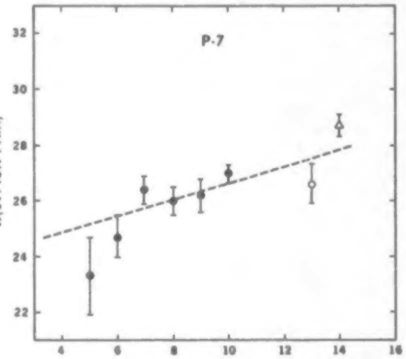

Fig. 3. Measured W-values as a function of heavy ion charge for primary heavy ions and fragments. *(XBL-826-10361)*

values for Ar and CH_4 from ICRU-31,[2] and the formula of Bortner and Hurst.[3] For both calculations $W_{\alpha,\beta} = 26.5$, in very good agreement with our average.

The data in Fig. 2 seem to have a statistically significant residual energy dependence that is different for each of the three fragments. This energy dependence is probably due to a systematic error in the delta-ray correction and not a property of W, since there are no immediately apparent reasons for such an energy dependence.

Figure 3 shows the measured W-values in P-7 as a function of heavy-ion charge, for primary heavy ions and fragments. The data for $z \leq 10$ were taken at an average energy of 603 MeV/A and the Al and Si points (taken at 400 MeV/A) have been adjusted to the same energy using the data of Fig. 2. The data are consistent with a linear dependence on z (shown by the broken line). A possible source of this apparent z-dependence may be columnar recombination, resulting in fewer ion-pairs collected and, hence, a higher value of W. On the other hand, if the residual energy dependence of W is an artifact, the uncorrected Al and Si points in Fig. 2 are ~4% lower and the data are consistent with a W-value independent of z.

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INCLUSIVE NEUTRON PRODUCTION BY ENERGETIC HEAVY IONS

Walter Schimmerling, R. Madey,* B.D. Anderson,* R.A. Cecil,† and P.C. Tandy*

Although the dose contributions of secondary protons and neutrons are small (in most beams less than 3%), these particles are an important source of background radiation in and around the medical cave, and quantitative information concerning these particles is essential. Such information is especially important when sensitive tissues are close to the treatment area, as in choroidal melanoma, a cancer of the eye, treatment for which is currently undergoing clinical trials at the 184-Inch Synchrocyclotron. Neutrons are also a penetrating component of high-altitude radiation, originating in interactions of cosmic rays with the atmosphere, where they constitute the most important source of exposure for passengers in high-flying aircraft. On a more fundamental level, neutrons are a unique probe of nuclear structure, being insensitive to the Coulomb fields of nuclei. In a series of experiments performed at the Bevalac, we have measured the probability (double differential cross section) of producing neutrons at a given energy and a given angle with respect to an incident heavy ion beam, when nuclei in the beam interact with nuclei in targets of carbon, aluminum, copper, lead, and uranium.

Taken together with the available data for emission of protons and light nuclei, our results provide constraints on physical assumptions underlying various models. The intranuclear cascade model of Stevenson,[1] which takes into account the total number of emitted neutrons and protons (i.e., those emitted as part of light fragments as well as those emitted as single nucleons), accounts quite

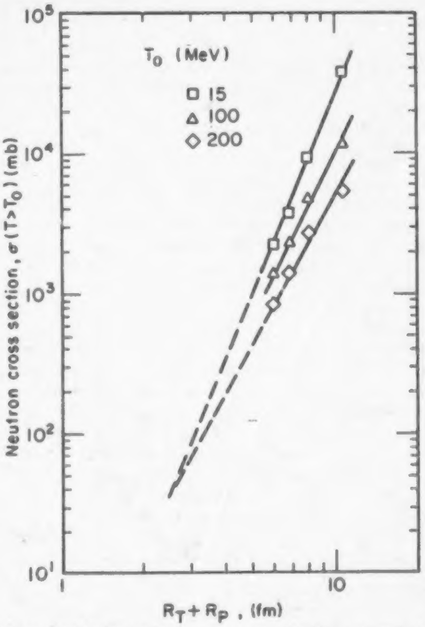

Fig. 1. Total inclusive neutron cross section plotted as a function of the geometric radius. (XBL 8211-4255).

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well for the observed n/p cross section ratios. The general features of the neutron spectra are consistent with the idea that the reactions start with individual, quasifree collisions between nucleons and then proceed toward equilibrium in subsequent interactions.

The total inclusive reaction cross section, $\sigma\,(T>T_0)$, integrated over all angles and over neutron kinetic energies, T, above a cutoff energy T_0 in the energy spectra, is shown in Fig. 1, plotted as a function of the geometric radius $R_C = R_T + R_P = r_0(A_T^{1/3} + A_P^{1/3})$, where $r_0 = 1.2$ fm and A_T and A_P are the numbers of nucleons in the target and the projectile, respectively. We find that $\sigma\,(T>T_0)$ is described by a power law of the form

$$\sigma\,(T > T_0) \;=\; \sigma_0\,(T_0)\left(\frac{R_C}{r_0}\right)^{\alpha(T_0)}$$

The coefficient σ_0 can be related to the nucleon-nucleon total cross section. The exponent extrapolates to a value of 5 for T_0 - 0, as would be expected in a geometric model. In such a model the integrated cross section is proportional to the product of the number of nucleons in a volume proportional to R_C^3 and a geometrical area proportional to R_C^2.

The multiplicity (i.e., number of neutrons per interaction) above an energy T_0 can also be calculated as the ratio $\sigma\,(T>T_0)/\sigma_R$, where σ_R is the nucleus-nucleus reaction cross section. We find that the neutron multiplicities calculated in this manner are comparable to proton multiplicities reported in the literature. Since the formulae were derived from data involving only neon at one energy, they will probably need to be modified when more data become available. In the absence of such data, these calculations are useful to estimate count rates and multiplicities for heavier projectiles and for the design of high-energy heavy-ion accelerator shielding.

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CORRELATED NEUTRON-PROTON EMISSION IN RELATIVISTIC HEAVY-ION INTERACTIONS

Kenneth A. Frankel,[*] Walter Schimmerling, John O. Rasmussen,[*] Kenneth M. Crowe,[*] James A. Bistirlich,[*] Roy R. Bossingham,[*] H. Bowman,[*] Osamu Hashimoto,[*] Don L. Murphy,[*] J. Ridout,[*] J.P. Sullivan,[*] Eunice Yoo,[*] William A. Zajc,[*] W. John McDonald,[‡] M. Salomon,[†] and J.S. Xu.[§]

Two types of models, the coalescence model and thermal equilibrium model have been in use to systematize the existing data on inclusive cross sections for the production of neutrons, protons, and light fragments. In turn, the relative abundances of neutrons, protons, and low mass composite nuclei have been used to test and refine these models. Thus, the measured cluster production together with the observed proton-inclusive cross section can be used to account for the unexpectedly large neutron to proton cross section ratio. Inclusive cross sections, however, are those where only one particle is observed experimentally, regardless of how many of the same or different type are produced in each reaction; all of the latter are included in the unobserved reaction products. It is thus of some interest to examine correlated neutron and proton pairs in order to ascertain the extent to which theoretical models can be used reliably to predict neutron production in relativistic heavy-ion interactions.

There are important physical reasons for studying the n-p correlation, since it is a measure of the existence

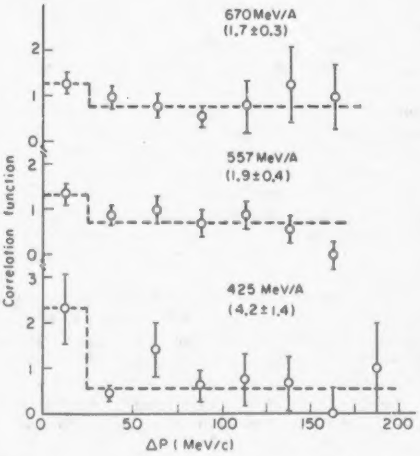

Fig. 1 *(XBL 8211-4256)*

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of a virtual deuteron singlet state. If the spins of neutrons and protons in a nucleus-nucleus interaction are randomly oriented and the temperature is large compared to the deuteron binding energy, then the ratio of triplet ("ordinary") deuterons to singlet virtual deuterons should be 3:1. However, if the spins between nearest neighbor neutrons and protons are correlated, as has been suggested might occur in the pion condensation phase of nuclear matter, then this ratio might be significantly different.

We have performed a preliminary measurement at the Bevalac of coincident neutrons and protons produced by relativistic neon ions incident on uranium. Charged particles were identified by their time of flight and their momentum (as determined in a magnetic spectrometer). Neutral particles were detected using a thick plastic scintillator, and their time of flight was measured between an entrance scintillator, triggered by the charged particle, and the neutron detector.

A correlation function can be obtained from the ratio of coincident n-p events and the randomized similar ratio between uncorrelated different events. The results obtained for the correlation are shown in Fig. 1, as a function of the momentum difference between the neutron and the proton momentum. The normalized values of the correlated function, obtained from the first bin, are 4.2 ± 1.4, 1.9 ± 0.4, and 1.7 ± 0.3 at 425, 557, and 670 MeV/A incident neon energy, respectively.

The apparatus was adapted from an experimental setup used in another experiment, and was not optimum for n-p studies. However, it was adequate to determine a correlation function for np pairs and to show the singlet deuteron signal above the uncorrelated np background, as seen in Fig. 1. Some information was also obtained about production rates, although absolute cross section determination will require a better measurement.

TRANSPORT STUDIES OF THE INTERACTION OF HIGH-ENERGY HEAVY IONS WITH EXTENDED MATTER

Mervyn Wong, Walter Schimmerling, and John W. Wilson*

The development of a theory for the transport of high-energy heavy ions through extended matter is crucial to our understanding of the effect of nuclear fragmentation processes on radiobiological studies and medical applications underway at this laboratory. To this end, a formulation using the Boltzmann equation and perturbation theory is being applied to the heavy-ion transport problem. Using this analytical method, we have developed a computer code that can be used to calculate the depth-dose relationship for heavy ions incident on bulk material, and to provide a quantitative description of the beam fluence, including the contribution arising from produced nuclear fragments, as a function of depth and particle energy.

Besides the questions of underlying physical interest which we are addressing in these transport studies, this effort is also important for two other reasons. Transport calculations are needed for the optimal design of beam line configurations for the proposed new medical accelerator.[1] They are also necessary for the detailed understanding of the spectrometer acceptance of our experiment in Beam 40 at the Bevalac.

The basic approach we have adopted is that advanced earlier by Wilson.[2] The charged-particle Boltzmann transport equation we write in the form

$$[\Omega \cdot \nabla - \frac{1}{A_j} \frac{\partial}{\partial E} S_j(E) + \Sigma_j(E)]\ \phi_j(\vec{x}, \vec{\Omega}, \vec{E})$$

$$= \sum_k \int dE'\ d\vec{\Omega}'\ r_{jk}\ (E, E', \vec{\Omega}, \vec{\Omega}')\phi_k(\vec{x}, \vec{\Omega}', E')$$

where $\phi j(\vec{x}, \vec{\Omega}, E)$ is the flux of ions of type j with atomic mass A_j at x with motion along Ω and energy E, $\Sigma_j(E)$ is the corresponding macroscopic cross section, $S_j(E)$ is the linear energy transfer, and $r_{jk}(E, E', \vec{\Omega}, \vec{\Omega}')$ is the production cross section for type j ions by the collision of a type k ion. This equation together with the appropriate boundary condition for the flux specifies the problem completely. Using perturbation theory, a series solution for ϕ_j is obtained in which we are able to identify each successive term as primary, secondary, tertiary, etc., contributions to the flux at a given depth of penetration. The physics input for r_{jk} is provided by the parameterization of Tsao and Silberberg[3] originally developed for cosmic ray work. A feature of particular interest is that we now have a method to assess the contribution of a specific nuclear fragment to the total dose.

The accompanying figures illustrate some of the results obtained to date. Figure 1 is a calculated Bragg curve for neon ions (A = 20, Z = 10) of energy 670 MeV per nucleon incident on tissue. The contributions to the total dose from the primary beam and from the first generation nuclear fragments are shown separately. The effects of multiple scattering and production angle have not been included, as well as those arising from finite beam and detector energy resolution. Each of these

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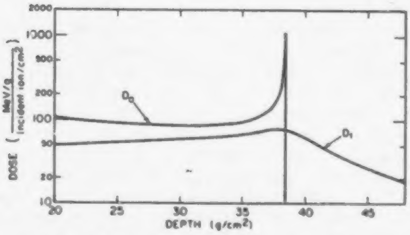

Fig. 1. Calculated Bragg curve for neon ions (A = 20, Z = 10) of kinetic energy 670 MeV per nucleon incident on tissue. D_0 is the dose from the primary beam. D_1 is the combined dose from all of the first generation nuclear fragments. It is seen that fragments contribute significantly to the total dose. Beyond the Bragg peak the dose is entirely due to fragments. *(XBL 8212-4305)*

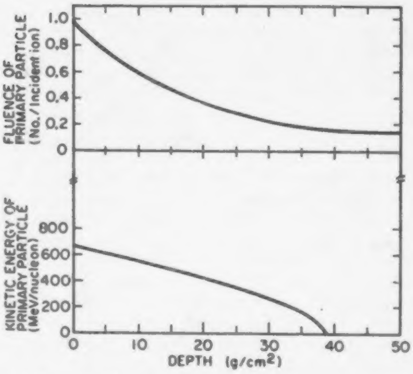

Fig. 2. Fluence and kinetic energy of primary particle as a function of penetration depth. These calculations are for neon ions (A = 20, Z = 10) of kinetic energy 670 MeV per nucleon incident on tissue. The range of these ions in tissue is 38.38 cm. Energy loss as particle traverses absorber is electromagnetic. Attenuation of primary particles is due to nuclear absorption. *(XBL 8212-4306)*

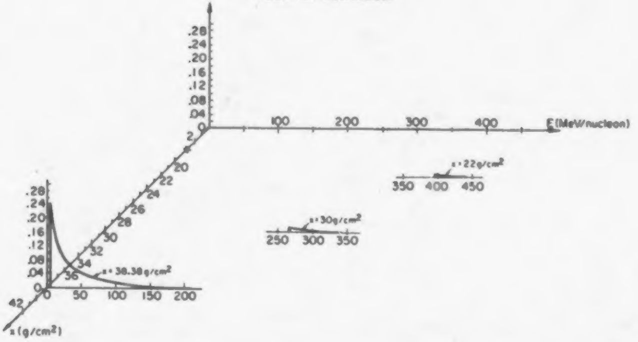

Fig. 3. Fluence of fragment (A = 19, Z = 9) as a function of fragment kinetic energy and depth of tissue. Beam ions are neon (A = 20, Z = 10) of kinetic energy 670 MeV per nucleon. Shown here are calculated energy spectra of fragment (A = 19, Z = 9) for three separate penetration depths: 22, 30, and 38.38 g/cm², respectively. The first two depth values lie on the plateau of the depth-dose distribution. The third value, x = 38.38 g/cm², corresponds to the Bragg peak. This plot dramatically illustrates the importance of fragment production near the Bragg peak, and the weighting of each energy spectrum toward lower energies, i.e., higher LET particles. *(XBL 8212-4307)*

will tend to broaden the Bragg peak and to lower its height relative to the plateau. The contribution beyond the Bragg peak is entirely due to fragments. This facet alone merits much more detailed study, which is presently in progress.

Figure 2 shows, for the same incident ion, the fluence of primary particles and their energy as a function of tissue depth. The treatment of energy loss is taken from the early work of Bethe,[4] with more recent refinements from various authors.[5-7]

Figure 3 shows the fluence of a specific fragment, in this case $A_{frag} = 19$, $Z_{frag} = 9$, as a function of fragment energy and tissue depth. There is a distribution of fragment energies at any given depth. Of particular interest is the weighting of this distribution towards lower energies, i.e., higher LET, with the concomitant influence on the dose.

The work in progress described here is still in its early stages. A number of important refinements have yet to be incorporated into the transport calculation. Among these is the inclusion of further terms in the perturbation series, e.g., those representing the tertiary fragments. The important effect of multilayers of homogeneous materials in the beam have yet to be studied, as does the finite energy resolution of the beam and detector. Finally, with the inclusion of three dimensional geometry and angular dependence of cross sections and multiple scattering, it is intended to extend the code to a fully three-dimensional one, spanning the entire domain of energy, ion-type, and spatial variables.

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RADIOLOGICAL PHYSICS AND CHEMISTRY

Aloke Chatterjee and John L. Magee

Studies made by the authors over the past several years on the fundamental nature of the chemical effects of high energy radiations have elucidated the role of track reactions[1,2] and have called attention to the fact that there are also multitrack effects in many irradiated systems.[3] Such effects are particularly expected in irradiated biological systems because radicals will usually be created with lifetimes longer than track lifetimes. We have studied, as an example, multitrack effects in the radiolysis of water because single track effects are so well known in water and experimental data are available for comparison with calculations based on our models. The principal objective is, of course, biological systems, and models are also being developed for the radiolysis of solutions of DNA.

The simplest approximation for treatment of multitrack effects is in terms of a system of homogeneous equations. These equations form a system of nonlinear ordinary differential equations (ODE) and they are based on all of the chemical reactions that occur. This system of ODE is extraordinarily difficult to solve because it involves such a wide range in orders of magnitude of concentration of species and in reaction rate constants. Such a system is called "stiff" and requires special techniques for solution[4]; in addition, the system arising here has a sensitivity to initial conditions that makes it "ill-conditioned stiff" with additional mathematical difficulties.

The ill-conditioned stiff equations at the heart of the multitrack-effect model can be solved using techniques developed by S.K. Dey.[4] We have investigated the water system for electron irradiation using 11 species (H_2O, e^-_{Aq}, H, OH, H_3O^+, OH^-, H_2, H_2O_2, O_2, O_2^-, HO_2) and 20 chemical reactions. Calculated results of an irradiation at 400 kilorads per minute are shown in Fig. 1. We see that the species vary in concentration by a factor of more than 10^8. Various rapid changes occur until a time of

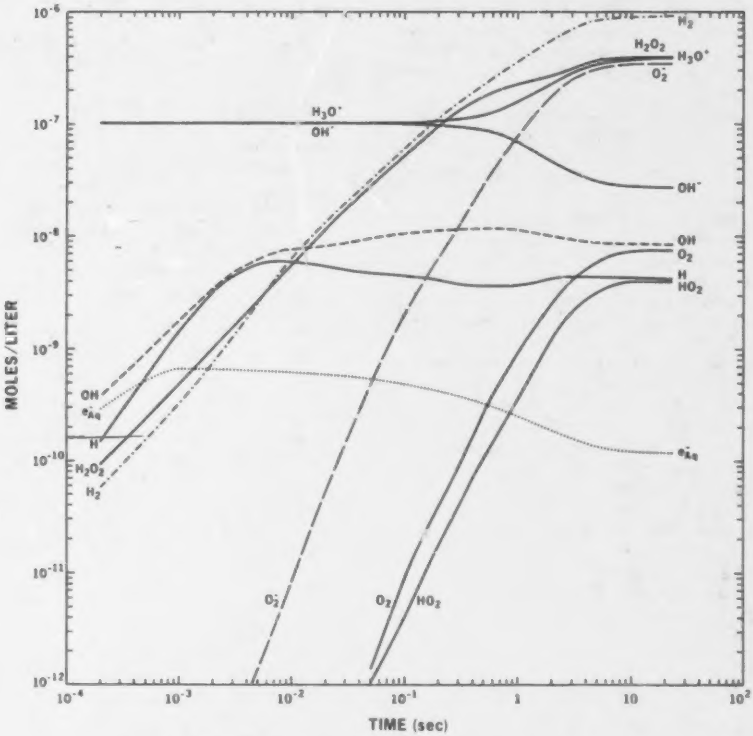

Fig. 1. Concentrations of species in neutral water (pH = 7) under γ-irradiation at 400 kilorads/minute. (XBL 824-8973)

about 10 seconds, after which the system is at a steady state that does not change further. The calculation yields much more information than experimentalists have measured, but the calculated results are in general agreement with what is known: irradiation lowers the pH of water; the conductivity is increased; the principal negative ion is O_2^-; etc. Other calculations on the decomposition of H_2O_2 and the reaction of H_2 with H_2O_2 have been found to agree with experimental results.

It is perhaps the most typical feature of radiation chemistry that so many different orders of magnitude (times, concentrations, reaction rates, etc.) are involved. In tracks we are concerned with early reactions that occur in less than a picosecond and establish inhomogeneous distributions of radicals that vary from local concentrations of species in the range of molar in the track core to micromolar in the fringes (penumbra)[1]; the chemical development of such a track requires a microsecond or so. We are involved in a collaboration with scientists at the Oak Ridge National Laboratory (ORNL) in an investigation of tracks by means of a Monte Carlo procedure. The results from this project will furnish a basis for the initial conditions in tracks and will also show how the radical diffusion stage develops.[5]

The fundamental radiation chemistry of DNA is of great importance in radiation biology. It is widely believed that strand breaks in DNA, particularly double-strand breaks, are involved in many deleterious effects of radiation on living cells. We are investigating the mechanism of strand breaks in DNA caused by all kinds of radiation, using the small circular molecules ϕX174 and SV40. At first the studies are purely chemical, using bare DNA in solutions of carefully controlled composition. In such systems the D_{37} for double-strand breaks, for example, varies from a few kilorads to several million rads. There is essentially only one mechanism for double-strand breaks: two independently-formed single-strand breaks are close enough to cooperate in breaking the molecules. In biological systems there may be other mechanisms for this process.

Circular DNA is a very sensitive system to use in such a study. We can determine the distribution of strand breaks as a function of conditions with great precision by means of electrophoresis. We can also use biological assays to compare chemical and biological measures of damage. The SV40 DNA can be obtained complexed with histones to give us a DNA that is very much like the DNA of chromatin found in living cells. Thus we expect to span the region between purely chemical and purely biological in the study of the radiation chemistry of DNA.

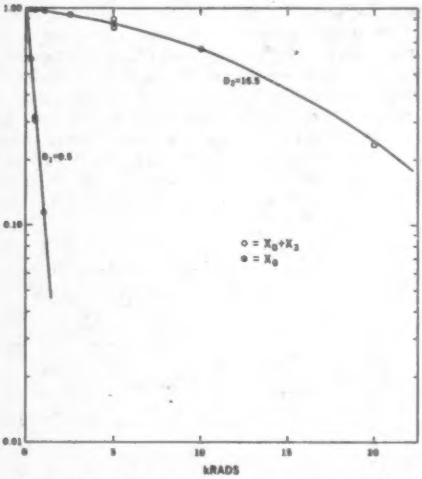

Fig. 2. Survival of X-174 molecules irradiated with γ-rays. X_0 gives the fraction that has no strand breaks; X_0 + X_1 gives the fraction that has no double strand breaks. *(XBL 825-9456)*

DNA has its greatest sensitivity to radiation in phosphate buffer solutions. Figure 2 shows curves for survival of SV40 DNA in phosphate buffer against single- and double-strand breaks vs. radiation dose for gamma rays. It is clear from the figure that survival against double-strand breaks has a dependence on the *square* of the absorbed dose. Analysis of the data shows that single-strand breaks on the adjacent strands must occur within 15 base pairs. We expect to find that the mechanisms of these breaks agree with physical and chemical studies that have been reported, and that we can use this information to explain the action of heavy particles on the same DNA solutions.

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RADIATION SURVIVAL STUDIES WITH CULTURED NORMAL HUMAN MAMMARY EPITHELIAL CELLS

Tracy C. Yang, Martha R. Stampfer, and Helene S. Smith*

The lethal effect of radiation on mammalian cells has been studied extensively since the development of the clonal assay by Puck et al.[1] Most radiation inactivation experiments have been performed with established mammalian cell lines, including human HeLa cells, due to limitation in the ability to culture normal human diploid epithelial cells. Survival curves of these established cells irradiated with x rays are, in general, exponential with a shoulder region at low doses. The survival curve of x-rayed normal diploid human cells, however, has been found to be different. By plating cells on feeder layers, Cox and Masson[2] obtained a high plating efficiency and studied the radiosensitivity of normal human fibroblasts to x rays. They found that the survival curves of cultured diploid human fibroblasts in exponential growth were unshouldered and exponential throughout. Since most human cancers are of epithelial origin and since women exposed to x radiation showed a higher incidence of breast cancer than the nonexposed female population,[3] it is important to know how normal epithelial cells respond to radiation. Recently we have developed techniques to grow normal human mammary epithelial cells in mass culture for 1 to 6 passages and in a highly efficient clonogenic assay. These technical advances have enabled us to study the radiation sensitivity of these cells. This report presents our recent experimental results with normal human mammary epithelial cells at second passage.

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Figures 1, 2 and 3 show the experimental results of normal human mammary epithelial cells from donors of three different ages, ranging from young (age 28) to old (age 56). The percent of cell survival is plotted as a function of x-ray dose. A total of eight doses, up to 900 rad, were used for each experiment. The survival curves appeared to be unshouldered and exponential. Experimental results are summarized in Table 1. The extrapolation number (n) of survival curve was about 1.0 for all cells studied. The D_0 varied from ~105 rad to ~135 rad, and the 10% survival dose (D_{10}) ranged from ~250 rad to ~320 rad. Cells from a 56-year-old donor (H191E) appeared to be slightly more sensitive to x rays than cells from younger ones, i.e., H164E and H208E. There was, however, no consistent trend in radiosensitivity with the age of donor.

For testing whether or not the normal human mammary epithelial cells can repair sublethal damage, we did fractionation experiments. Cells (H208E) were irradiated either with single doses or with a first dose of 225 rad, incubated for 4.5 hours at 37°C, and then exposed to second doses of 75, 150, 225, and 300 rad. Figure 3 shows the experimental results. For an equal dose, there was no significant difference in survival between cells exposed to single or split doses. For cells irradiated with split doses, a first dose of 225 rad and a second dose of 225 rad after 4.5 hours incubation at 37°C, for example, gave a survival about the same as that receiving single dose of 450 rad, namely ~3%. Results therefore suggest that normal human mammary epithelial cells may not be able to repair sublethal radiation damage.

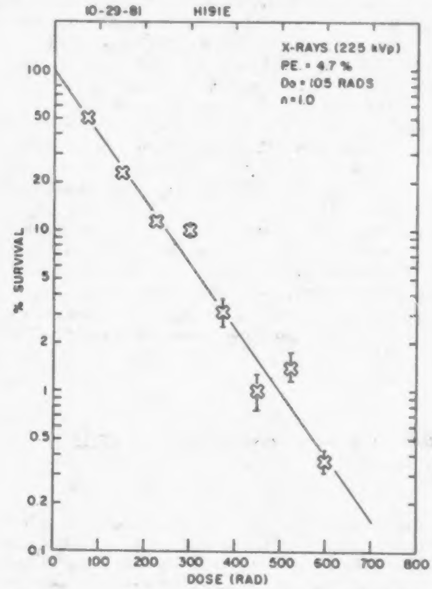

Fig. 1

(XBL 821-7708)

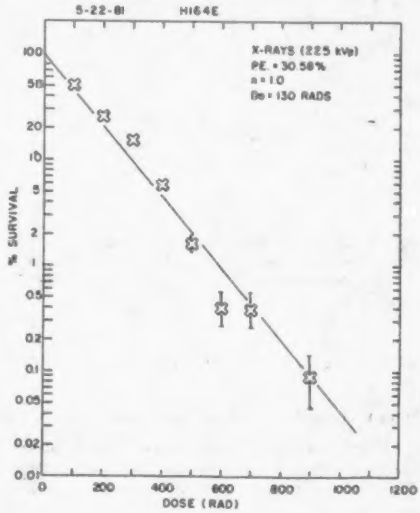

Fig. 2

(XBL 821-7707)

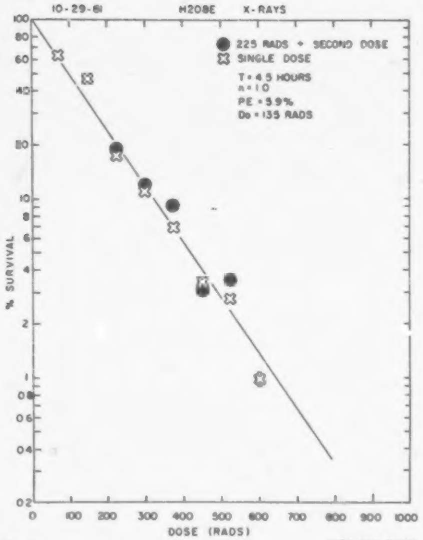

Fig. 3 (XBL 821-7698)

An unshouldered exponential curve appears to be the best fit of these 13 data points with a D_0 of about 135 rad.

Our experimental data have demonstrated that the survival curve of normal human epithelial cells irradiated with x rays is an exponential one with no shoulder and with a D_0 of 105–135 rad. These results are comparable to those reported for normal human fibroblasts. For example, Weichselbaum et al.[4] reported that normal human diploid skin fibroblasts showed a D_0 of 132 rad.

The shoulder of a survival curve has been commonly interpretated as an accumulation of sublethal damage before the lethal effect can be expressed. The repair of sublethal damage in mammalian cells has been investigated extensively by measuring the increase in survival observed following administration of two fractionated doses compared to the survival after an acute exposure to the same total dose. This repair is termed "Elkind recovery." In cells that do not have a shouldered survival curve, no sublethal damage repair is usually observed with the split-dose technique. Since the survival curve of normal human mammary epithelial cells is unshouldered and exponential, one would expect no sublethal damage repair in these cells, and our results from split-dose experiments are consistent with this prediction.

Table 1. Radiosensitivity of normal human mammary epithelial cells to 225 kVp x-rays.

Cell specimen	*Age of donor (yr)*	*n*	*D_0 (rad)*	*D_{10} (rad)*
H164E	28	1.0	130	300
H208E	45	1.0	135	320
H191E	56	1.0	105	250

In summary, our data indicate that the x-ray survival curve is an exponential one with no shoulder, that there is no consistent change in radiosensitivity of cells with the age of donor, and that there is no detectable sublethal damage repair in normal epithelial cells.

Since the survival curve is unshouldered and exponential, our results suggest that there may be no threshold dose of x rays for killing normal human epithelial cells. More experiments, however, need to be done before one can make a final conclusion. In the coming year, we are planning to investigate the lethal effect of low dose rate, the potential lethal damage repair, and the potential mutagenic effects of radiation on these cells. This information may be valuable for our understanding of and estimating the potential radiation risk at low dose level.

ACKNOWLEDGMENT

We wish to acknowledge the excellent technical assistance of Ms. A. Pang, Ms. L. Craise, and Mr. S. Sylvester.

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CARCINOGENIC AND MUTAGENIC EFFECTS OF ENERGETIC SILICON IONS ON CULTURED MAMMALIAN CELLS

Tracy C. Yang, Laurie M. Craise, Jerry Howard, and Cornelius A. Tobias

The potential carcinogenic and mutagenic effects of energetic heavy ions, which are present in cosmic rays, are not well understood. In our laboratory, we are studying the effects of energetic heavy particles on somatic mutation and malignant transformation of mammalian cells to obtain quantitative information on the dose-response curves and RBE values for heavy ions with various energies and LETs, to determine the kinetics and nature of potential transformation damage repair, and to understand the fundamental mechanism(s) of neoplastic cell transformation by heavy ions. The present report describes experimental results we have obtained with high energy silicon ions accelerated at the Bevalac.

The cell system used for these studies is C3H10T1/2, an established line of mouse embryo cells widely used to assay neoplastic transformation *in vitro*. Well confluent G_1 cells were irradiated with x rays or a silicon ion beam. The initial energy of the silicon beam was 320 MeV/u, and the residual range in water, the ion energy, and the LET of the beam at the cell sample position were about 4.5 cm, 240 MeV/u, and 84 keV/μm respectively. Immediately after irradiation cells were plated into 100-mm tissue culture dishes at low density. The dishes were incubated at 37°C for two weeks to determine the colony-forming ability and for six weeks to check the transformation frequency. After carefully scoring all dishes, data were subsequently analyzed and plotted.

A comparison between x rays and silicon ions in causing cell killing is shown in Fig. 1. Data gave an RBE value of about 3.0 at 50% survival level. For neoplastic cell transformation, a linear plot of experimental results is given in Fig. 2. The RBE determined at the level of transformation frequency induced by a 50% survival of x-ray dose is also about 3.0.

The role of repair in radiation induced lethality and cell transformation was also studied. Part of the lethal damages induced by silicon ions appears to be repairable in confluent G_1 cells. Survival is about 40% higher in cells irradiated by a silicon beam and incubated for one day before being trypsinized and plated at a low density (Fig. 3). The repair ratio (the ratio of doses between cells plated immediately and 1 day later at a given survival level) is about 1.4 at both 50% and 10% survival levels. Cells irradiated with x rays showed a higher repair ratio, about 1.7 (Fig. 4). Lethal damage induced by silicon ions, therefore, seems to be less repairable in G_1 cells than that induced by x rays.

A significant amount of repair of transformation lesions in x-rayed cells plated one day after irradiation was

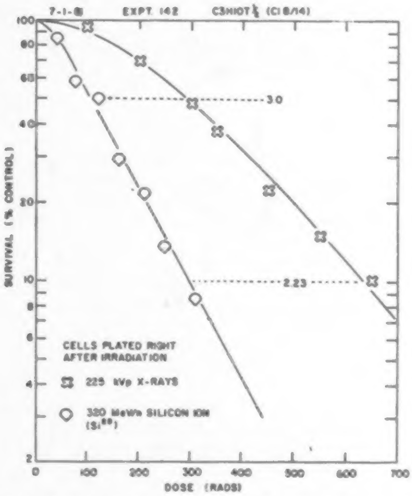

Fig. 1. Survival curves of G_1 cells irradiated by x rays or energetic silicon ions. Cells were plated right after irradiation.

(XBL 8110-7112)

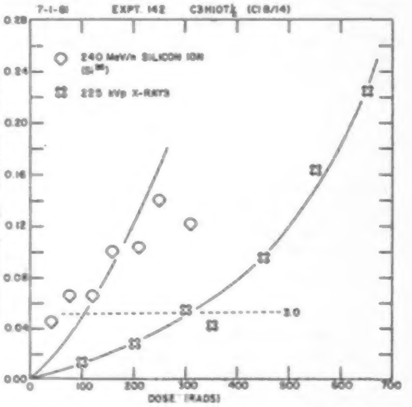

Fig. 2. Neoplastic cell transformation induced by x rays or an energetic silicon beam. Cells were plated right after irradiation.

(XBL 8110-7109)

observed, as shown in Fig. 5. Cells plated about one day after irradiation gave a transformation frequency per survival about half as much as that plated right after irradiation. This large decrease of transformation frequency in cells incubated for one day before being plated is in good agreement with the experimental results on the kinetics of repair in x-rayed cells obtained and reported earlier. A very interesting finding from this silicon experiment is that *no* repair of transformation damage could be detected in cells irradiated by silicon ions. The cell transformation dose response curves for silicon ion irradiated cells plated immediately or one day after irradiation are the same, as shown in Fig. 6. This observation suggests that the RBE for cell transformation will be significantly greater for slow growing cells than for fast proliferating ones irradiated with heavy ions with LET greater than 100 keV/μm. These results also indicate that cell transformation lesions may not relate to potential lethal damage at all. Recently repairable double strand DNA break (d.s.b.) has been suggested as possible potential lethal damage (p.l.d.).[1] If this hypothesis is correct, our results then indicate that the transformation lesion is not a simple repairable d.s.b. Some unidentified misrepaired DNA damage may be responsible for the radiogenic cell transformation.

The mutagenic effect of 320 MeV/u silicon ions was studied with a subline of C3H10T1/2 cells—SV10T1/2.

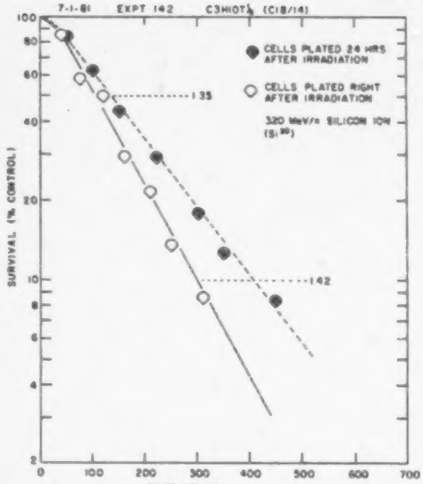

Fig. 3. Potential lethal damage repair in G_1 cells irradiated with silicon particles. *(XBL 8110-7111A)*

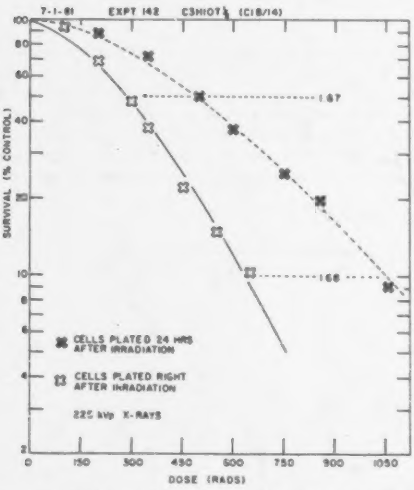

Fig. 4. Repair of potential lethal damages, due to delayed plating, in x-rayed confluent cells. *(XBL 8110-7114)*

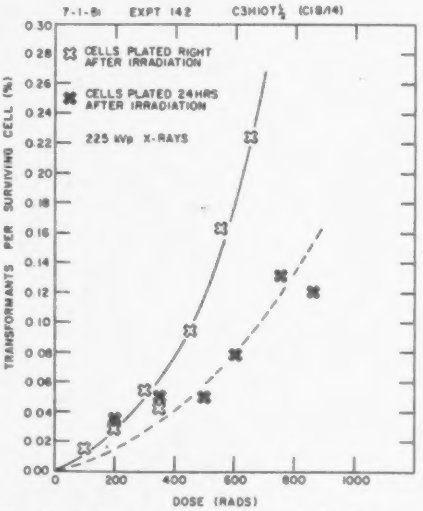

Fig. 5. Repair of transformation lesions in x-rayed cells. The transformation frequency decreased significantly when cells were plated one day after irradiation. *(XBL 8110-7108)*

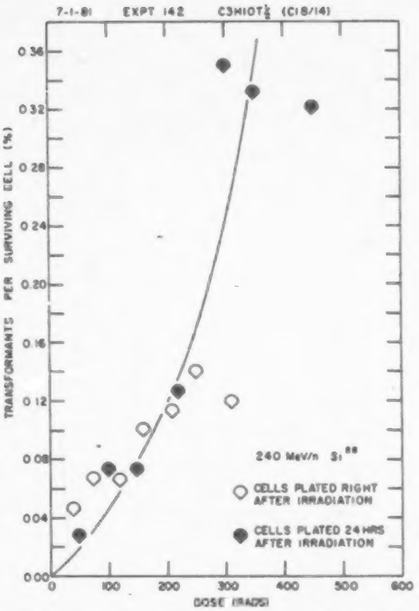

Fig. 6. Comparison between cells plated right after and one day after silicon ion irradiation. Delayed plating showed no effect on the transformation frequency. *(XBL 8110-7107)*

This subline was established by isolating a clone of C3H10T1/2 cells transformed by SV40 viruses. In terms of cell killing, SV10T1/2 cells showed no difference in radiosensitivity from their parental line—nontransformed C3H10T1/2 cells. Using the respread technique, we investigated the induction of 6-thioguanine-resistant mutation by silicon particles. Some preliminary results are shown in Fig. 7. High-LET silicon ions, for a given dose, appeared much more effective than x rays in producing deletion type HGPRT (hypoxanthine-guanine-phosphoribosyltransferase) mutation in mammalian cells.

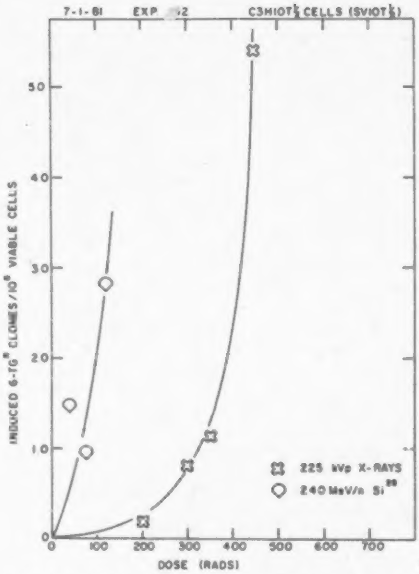

Fig. 7. Induction of 6-thioguanine-resistant mutation by x rays or high energy silicon particles. *(XBL 823-8342)*

We are keenly interested in the fundamental aspects of the cell transformation lesion and believe that some insights can be obtained through the heavy-ion cell transformation and mutation studies. An understanding of the molecular nature of the cell transformation lesion is clearly important for elucidating the mechanism(s) of radiation carcinogenesis and for assessing the radiation risk.

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CELLULAR AND MOLECULAR RADIOBIOLOGY OF HEAVY-ION BEAMS

Cornelius A. Tobias, Eleanor A. Blakely, Ruth J. Roots, Tracy C. H. Yang, Polly Y. Chang, Leora Lommel, Lauri M. Craise, Michael J. Yezzi, and Peter M. Martin

The role of the cellular and molecular radiobiology group is to develop a fundamental understanding of the manner in which heavy ions exert their effects on biological systems, to apply our knowledge for a rational approach to therapy with heavy ions, and to quantitate the dose-effect relationships for acute and chronic effects in order to assure safe treatments. Since we do not fully understand the differences between tumor cells and normal cells, these tasks are challenging.

We are now engaged in investigating specific aspects of cell injury produced by radiation lesions, and in comparing cell injury at different phases of the cell division cycle. Figure 1 is a schematic drawing of the cell division cycle and the effects of heavy ions and x rays at the different phases. One should visualize that the cells of the tissues are progressing in time clockwise as represented in the graph. However, many normal cells in differentiated tissues reside in the G_0 phase, represented here as following mitosis, and these cells may not participate in the full cycle. Many tumor cells are in G1 phase at any given time, but because the G_0-G_1 boundary either does not exist or is weak, tumor cells are more free to follow the

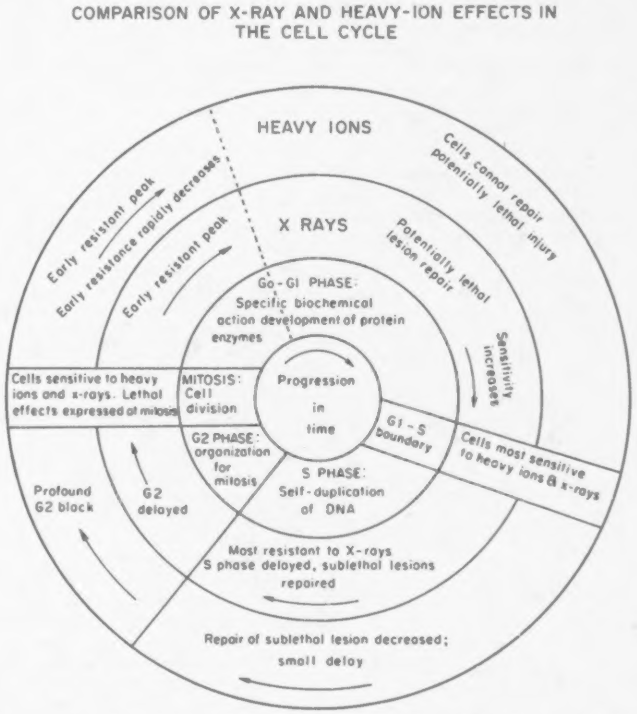
COMPARISON OF X-RAY AND HEAVY-ION EFFECTS IN THE CELL CYCLE
HEAVY IONS
X RAYS
Early resistant peak
Early resistance rapidly decreases
Early resistant peak
Cells cannot repair potentially lethal injury
Potentially lethal lesion repair
Sensitivity increases
Go-GI PHASE: Specific biochemical action development of protein enzymes
Progression in time
Cells sensitive to heavy ions and x-rays. Lethal effects expressed at mitosis
MITOSIS: Cell division
G2 PHASE: organization for mitosis
S PHASE: Self-duplication of DNA
G1-S boundary
Cells most sensitive to heavy ions & x-rays
Profound G2 block
G2 delayed
Most resistant to X-rays S phase delayed, sublethal lesions repaired
Repair of sublethal lesion decreased; small delay

Fig. 1. Schematic drawing of the cell division cycle. The inner ring shows the phases of the cycle and the DNA activity during each specific phase. The middle ring shows the effects at each phase if the cells are irradiated with x rays; the outer ring shows the effects of exposure to heavy ions. *(XBL 8212-4302)*

cycle. Generally, resistance to x rays is highest in S and early G_1 phases. Heavy ions increase radiosensitivity through the entire cycle, and particularly reduce repair in G_1 and S phases.

We already have evidence that small doses of heavy ions can produce more lethal effects than equivalent absorbed doses of x rays. We also know that heavy ions are particularly effective in reducing repair in the G_1 phase, and somewhat less effective in reducing S phase repair. X rays delay progression through the S and G_2 phases, whereas heavy-ion irradiation is characterized by a prolonged block in G_2, just before mitosis. When normal cells are in contact, they mutually inhibit each other's progression through the cell cycle, frequently resulting in a piling up of cells in G_1 phase; tumor cells are not so inhibited.

The studies described in the paragraphs that follow represent progress in our understanding of the various details of these complex cellular phenomena.

FRAGMENTATION EFFECTS ON RBE AND OER

Fragmentation of primary heavy charged particles into secondary particles of predominantly lower charge and mass occurs as a result of nuclear interaction events that take place when particles traverse absorbing targets. We have investigated the effects of fragmentation events on the aerobic and hypoxic cell survival of asynchronous human T-l cells *in vitro* under conditions where the dose-average LET of the primary ions is approximately 118 keV/μm, as confirmed by several dosimetric methods.

Particle beams of two different initial energies, but with the same atomic number, have been studied in track segment experiments. A beam with an initial low energy usually has a small fragmentation component, whereas a high initial energy of the same primary ion can be selected which has a larger fragmentation component. Measurements of relative biological effectiveness (RBE) and oxygen enhancement ratio (OER) were made at a residual range of 0.54 cm of water in neon beams of two energies (225 MeV/u and 670 MeV/u), and at a residual range of 1.87 cm of water in silicon beams of two energies (320 MeV/u and 670 MeV/u).

Preliminary results indicate that the dilution of the primary beam dose average LET by the secondary particles of low LET resulted in a reduced effective total beam LET. The effect of this change in the physical characteristics of the high energy beams was to decrease the RBE but not to significantly change the OER, relative to the measurement of these values in the low energy beams. This is demonstrated in Fig. 2 for RBE and OER measurements made at various residual ranges in silicon beams with initial energies ranging from 320 MeV/u to 670 MeV/u.

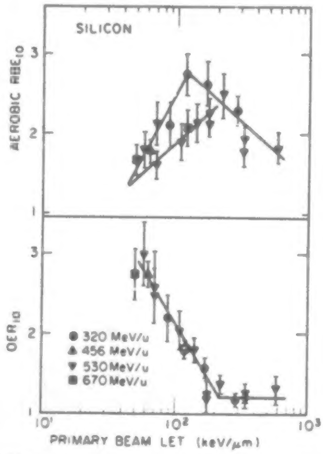

Fig. 2. RBE and OER measurements made at various residual ranges for silicon beams ranging in initial energies from 320 to 670 MeV/u.
(XBL 8211–4238)

HEAVY-ION CELL CYCLE EFFECTS

Synchronized cell populations of Chinese hamster V-79 and human T-1 cells have been studied to characterize the cell ages that are sensitive and resistant to heavy-ion damage. The data collected have confirmed that high-LET radiation diminishes the differences in radiosensitivities between cell ages, which results in more similar dose responses for cell killing at all phases of the cycle of DNA synthesis, especially at low doses. The human and hamster cells were selected for this study because a large body of accumulated information on their asynchronous response to Bevalac accelerated heavy ions already exists, and because we have an interest in comparing cell lines with abbreviated and prolonged G_1 phases. The longer G_1 phase is characteristic of many human cell lines; it is also characterized by a low-LET radioresistance that is fundamentally of interest from a target point of view and may also have clinical significance in terms of evaluating dose fractionation schedules.

Figure 3 shows whole x-ray and neon-ion dose-response curves of synchronized human T-1 cells. Computer assisted least-squares fits to the linear quadratic model are shown. At 10% survival the RBE values are 1.4 for mitotic cells, 3.2 for G_1/S phase cells, and 2.8 for late S-phase cells. Two separate experiments are represented for each curve, except for the mitotic neon curve which represents data from a single experiment.

Consistent with the age response profile, the G_1/ early S-phase cells are more sensitive than the mitotic/ early G_1 phase cells. This is seen more clearly in Fig. 4,

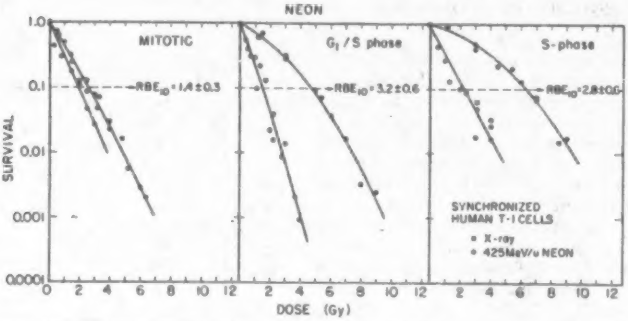

Fig. 3. X-ray and neon-ion dose-response curves for synchronized human T-1 cells. *(XBL 824–3752)*

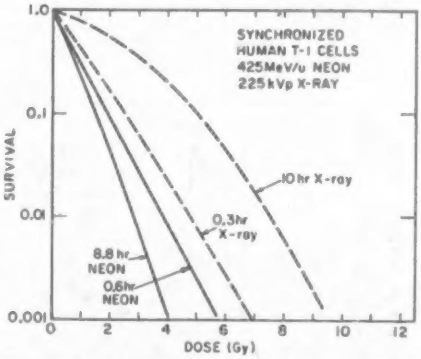

Fig. 4. Synchronized human T-1 cells exposed to x rays or heavy ions: the dose response curves show that the Gl/early S phase cells are more sensitive to Bragg peak neon ions than are the mitotic/early Gl phase cells; whereas the reverse is true for the x-ray responses.
(XBL 824–3746)

which shows that the mitotic x-ray and neon curves have an intermediate radiosensitivity between the very sensitive G_1/S phase neon response and the approximately same aged G_1/S phase x-ray response.

Figure 5 depicts the age response profile for an x-ray and a neon-ion experiment, each of which kill to approximately the 1% survival level, but with a much lower neon ion dose. The main conclusion of this preliminary report of synchronized human cell response to neon ions is that beyond the G_1/S border (indicated by points to the right of the cross-hatched line), both x rays and neon ions show a radioresistant S phase population. In contrast, however, at cell ages before the G_1/S border (indicated to the left of the cross-hatched line), the age response profile of mitotic/early G_1 phase cells is quite different for neon and x-ray irradiations. We are planning to examine these early cycle differences in greater detail in the future, and we will be analyzing the cross-sectional dependence of the radioresponse of synchronized human cells.

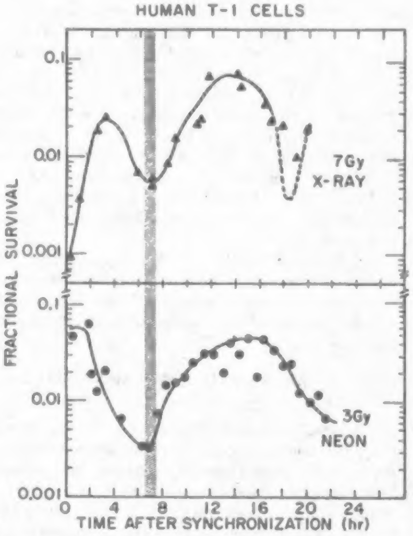

Fig. 5. Synchronized human T-1 cell age-response profile for an x-ray and a neon-ion experiment. *(XBL 824–3745)*

REPAIR OF POTENTIALLY LETHAL DAMAGE IN CONFLUENT CELLS

The question "how much radiation damage can be repaired in mammalian cells" is a fundamental one. Survival curves obtained by conventional techniques usually do not give information on either the initial amount of injury or the maximum repair of damage in irradiated cells. However, recently it has been possible to inhibit some of the enzymes responsible for repair of the radiolesions, and such experiments shed light on the yield of radiolesions as well. In the experiment described below, we inhibit a DNA beta polymerase with β-D-arabinofuranosyladenine (β-araA). To determine the amount of repairable and irrepairable damage, we used mouse embryo cells (C3H10T1/2). Confluent cells were x-rayed, then treated in three different ways: one group of cells was seeded at low density in regular medium, one group was incubated at confluent state for one day before being plated into regular medium, and one group was plated into β-araA medium (100 μm) that was replaced with regular medium one day later. Colonies formed after two weeks of incubation were counted, and the results are shown in Fig. 6. The survival curve for cells treated with β-araA is an exponential one with no shoulder, and the LD_{50} and LD_{10} are about 100 and 360 rad, respectively. At the 50% survival level, β-araA treated cells appear to be about five times more radiosensitive than cells allowed maximum repair. The dose modifying factor, however, varies with the survival level: decreasing with increasing doses.

Cells trated with β-araA also showed a higher frequency of neoplastic cell transformation than control cells. Results are given in Fig. 7. This result suggests that a radiation-induced cell transformation lesion may be in the DNA.

REPAIR OF X-RAY DAMAGE IN A MAMMALIAN CELL MUTANT

A protein synthetic mutant of a Chinese hamster ovary cell line designated TSH1 and the wild type cell designated SC1 have been characterized with respect to their ability to carry out protein synthesis when they are treated with mild hyperthermia.[1] The mutant cell line but not the wild type has been shown to rapidly shut down protein synthesis when it is transferred from its normal growth temperature of 35°C to 40°C. Our first goal was to examine the effect, if any, that interruption of protein synthesis had on the rapair of sublethal x-ray damage (SLD). We discovered that the repair of SLD could be reduced if the cells were first placed at a high temperature for a minimum of 2 hours before the first dose of x rays and if the inhibition of protein synthesis was continued until the second dose was given. We interpreted this to mean that a pool of protein was nec-

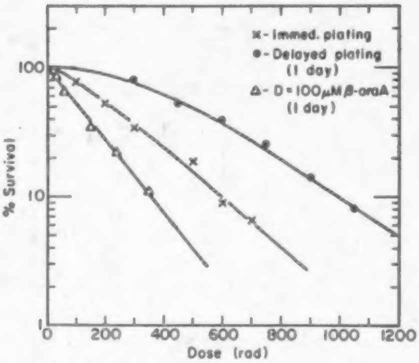

Fig. 6. Survival of C3H10T½ cells exposed to 225 kVp x rays, and then (x) immediately plated, (●) delayed plated, or (Δ) treated with β-araA (XBL 8212–4293)

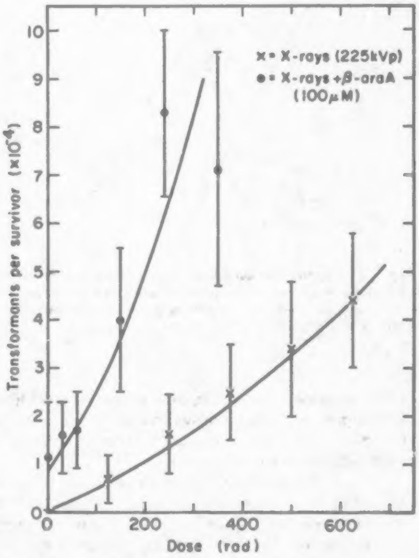

Fig. 7. Cell transformation as a function of dose with and without the addition of β-araA. C3H1OT½ cells were either exposed to 225 kVp x rays alone (x) or exposed to x-rays and then treated with β-araA (●) The cells were then incubated, and the colonies were examined for neoplastic cell transformation. (XBL 8212–4294)

essary for repair and only upon depletion of it would any effect on cell survival be seen.

Our second goal was to obtain a clearer understanding of the relationship between molecular and cellular events going on inside the cell, after exposure to x rays. Since DNA is a primary target for radiation damage leading to cell lethality, we decided to observe what effect the lack of protein synthesis, which affected cell survival, would have on the rejoining of breaks in DNA. S. Okada (Tokyo, Japan) brought to our attention a technique for observing breaks in DNA after low doses of x rays (less than 1000 rad) patterned after the work of B. Rydberg.[2] Briefly, the technique involves exposing irradiated cells prelabled with ^{14}C-TdR to an alkali solution to disrupt the cells and to cause unwinding and denaturation of the DNA at the sites of breakage. The mixture is then neutralized and sonicated to break up the DNA. The single and double strands of DNA are separated from each other on a hydroxylapatite column by eluting through different concentrations of phosphate buffer. As the dose of radiation increases, the fraction of single stranded DNA coming off the column increases. The amount of each type of DNA can also be followed as a function of time after exposure to a fixed dose of x rays.

Because this technique allows the use of doses in the range of cell survival measurements, we felt that a more meaningful correlation between DNA rejoining and cell survival could be made. In the split dose x-ray experiments shown in Fig. 8, we used the same temperature and time scheme for the DNA rejoining as the earlier cell survival experiments. We did not see any effect on DNA rejoining as we did for cell survival when protein synthesis was inhibited. We interpret this to mean that the enzymes involved in rejoining DNA are not affected by the lack of protein synthesis that reduced the repair of SLD. Another possible role of protein synthesis in the repair of SLD may involve proteins that are essential for the correct expression of the DNA. We intend to explore this idea with the use of synchronized cells.

INDUCTION AND REPAIR OF DNA LESIONS: *IN-VITRO* AND *IN-VIVO* WORK WITH THE SIMIAN VIRUS 40

Some of our molecular work during the past year has concentrated on the LET-dependent induction of double-strand breaks in DNA. For this purpose we have used the simian virus 40 (SV40) genome. Chromatographic assay systems developed in our labratory allow distinct separation of single- and double-strand break yields, either from the SV40 DNA solution or the SV40 DNA recovered from a mammalian host cell.

Irradiation of SV40 DNA in solution with accelerated particles of different masses and/or velocities, giving a spectrum of ionization densities, show that about 25 single-strand breaks are produced for each double-strand break after gamma-ray irradiations. As the ionization density increases, this ratio changes such that at very high LET, about 10 single-strand DNA breaks are made for each double-strand break.

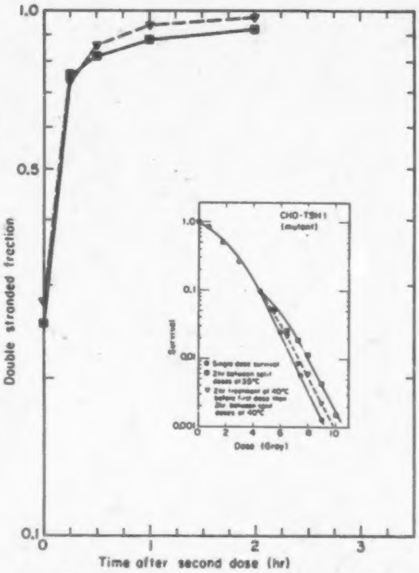

Fig. 8. Split x-ray dose cellular and molecular data using the Chinese hamster CHO-TSHI mutant protein synthesis cell line.

(XBL 821-3538)

It is, however, of greater interest to determine these DNA lesions in cellular DNA, and such studies are currently under investigation. In a mammalian host cell where SV40 propagation goes on, the SV40 genome is structurally identical to mammalian chromatin, except for its much smaller size. Figure 9 shows the effects of x-ray irradiation on intracellular SV40 chromatin. In the electrophoretograms, the peaks of mammalian DNA are shown in the cross hatched area. In the second electroretogram from the top only a very minor peak for the mammalian DNA is present in the uninfected cell lysate, and it is only after irradiation that the host cell DNA becomes noticable. The third electrophoretogram from the top shows the SV40 DNA profile from the lysate of infected African green monkey cells, the large peak representing the maximally supercoiled molecule and the small peak representing molecules that have one or more single-strand breaks. After irradiation this peak increases.

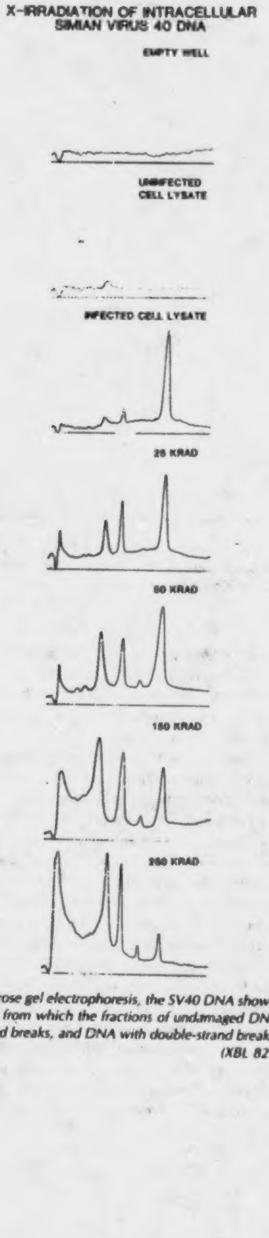

Fig. 9. After agarose gel electrophoresis, the SV40 DNA shows a characteristic profile from which the fractions of undamaged DNA, DNA with single-strand breaks, and DNA with double-strand breaks can be quantified. *(XBL 823–8627)*

The third peak in the middle represents linear DNA, that is, molecules having a double-strand break. We are currently measuring the fraction of DNA molecules with these two types of lesions (single-strand breaks and double-strand breaks) to determine the number of single-strand breaks formed per double-strand break as the breaks occur inside the cell nucleus.

STUDIES OF RADIOSENSITIZATION BY DIAMIDE

Cellular x-ray survival studies with the chemical radiosensitizing agent diamide have been conducted in order to determine how diamide achieves its radiosensitizing effect. This agent, best known as a rapid oxidant of sulfhydryl compounds (notably glutathione) and of the pyridine nucleotides (NADH and NADPH), has also been shown to have radiochemical reactivity comparable to other hypoxic cell sensitizers that have a nitroheterocyclic structure. Both a slope increase and a shoulder removal of the mammalian cellular survival curve have been previously reported for diamide under selected conditions. These observations suggest that diamide may act as an electronaffinic agent, which could increase the free radical mediated damage resulting from radiation, and/or it may act as a biochemical oxidizing agent, which could prevent cellular repair processes.

It was the intent of the present work to determine just what conditions were needed to observe shoulder reduction of the cellular survival curve, and to resolve the mode, or primary modes, of action of diamide. In these experiments, conducted mainly with Chinese hamster V79 cells and 225 kVp x rays, the radiosensitizing effects of a 15-minute incubation with 0.2mM diamide were determined at 4°C, 21°C, and 37°C, under hypoxic and aerobic conditions, and when diamide was added just after irradiation, as well as 5–10 minutes before irradiation. In all cases, a reduction in the slope of the survival curve was seen. The aerobic radiosensitization of diamide was consistently dose modifying, with an enhancement ratio of 1.6 or less. The most dramatic reduction occurred in hypoxia, as expected, at 4°C and 21°C, with diamide present during irradiation. Removal of the shoulder of the hypoxic survival curve occurred at 4°C when diamide was added before or just after irradiation, and at 21°C when diamide was added shortly before irradiation.

The age response of synchronous T-1 cells with 400 rad of x rays and diamide was also studied. Results depicted in Fig. 10 indicated a uniform decrease in survival over the cell cycle. No cell age dependence of diamide radiosensitization was evident.

These studies indicate that 1) the degree of radiosensitization by diamide is strongly dependent on temperature and timing of drug administration, 2) removal by diamide of the shoulder of the survival curve occurs

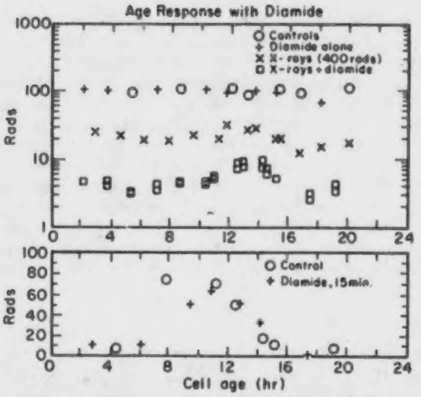

Fig. 10. (Upper) Percent survival of human T-1 cells to 225 kVp x rays with and without diamide treatment as a function of cell age in hours after mitotic selection. (Lower) Percent of ^{3}H-TdR labeled T-1 cells as a function of cell age in hours. The diamide treatment was at a concentration of 0.2 mM for 15 min starting 5 min before irradiation, and extending to about 5 min after irradiation. *(XBL 8212–4301)*

only under limited conditions, and 3) radiosensitization from diamide treatment immediately after irradiation is comparable to radiosensitization from diamide treatment during irradiation.

The results are interpreted to mean that diamide acts primarily by inhibiting repair processes. Diamide presence just after aerobic irradiation resulted in only a small change in the slope of the survival curve, compared to its effect when present during irradiation. Diamide presence just after, as well as during hypoxic irradiation at 4°C and 21°C resulted in shoulder removal. The preliminary age response result suggests that the effect of diamide may be different than that of another well-known radiosensitizer and sulfhydryl reagent, N-ethylmaleimide.

MODELING CELLULAR AND TISSUE RESPONSES TO DELETERIOUS AGENTS

In order to achieve a quantitative understanding of the mechanism by which deleterious and carcinostatic agents act, it is important to have mathematical models. Many of the radiobiological models in the literature have stressed the physical interactions of radiation with matter but less attention has been given to the repair responses of cells to injury.

The repair-misrepair (RMR) model developed in our laboratory separates the interactive processes that produce key molecular lesions from the enzymatic repair processes that occur in the postexposure period. The model is based on the simple assumption that the enzymatic informational apparatus of the cell recognizes molecular modes of injury and, in the course of time, attempts to enzymatically repair the damage. The fidelity of repair is important, and mistakes made in the repair processes lead to the consequences of injury: lethality, cell transformation, or the appearance of variants. The RMR model can be used at three different levels to aid research: At the biochemical level it helps to analyze the chemical yield of molecular lesions, for example strand breaks produced in DNA. At the cellular level, by analysis of split dose experiments, its use can determine the time rate of repair; because different repair processes usually proceed at different rates, one can sometimes separate various processes from each other. In Fig. 11, we illustrate these principles by showing x-ray survival curves of several strains of mammalian cells: cells that are genetically deficient in repair from a patient suffering from ataxia telangiectasia, from normal human cells (IMR-90) and from human kidney cells that have an efficient repair capacity. In addition, normal mouse cells have been studied wherein repair has been inhibited by application of an inhibitor of the enzyme beta-DNA polymerase, which is believed to be involved in the repair of potentially lethal damage.

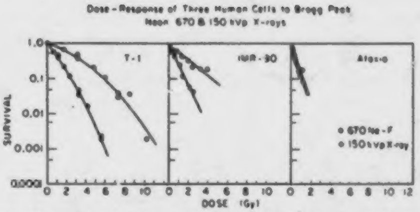

Fig. 11. Neon-ion and x-ray survival curves for three human cell lines: (left) human T-1 kidney cells that have an efficient repair capacity; (middle) normal human cells (IMR-90); (right) human cells that are genetically deficient in repair obtained from a patient suffering from ataxia telangiectasia. *(XBL 8211–4246)*

Various human tissues show an array of sensitivities to the same deleterious agent. For example, cells from gut epithelium have substantial repair capaicty, bone marrow colony forming units repair less, and repair seems to be absent from spermatogonial cells of the testes. Neurons, which have a long life span in the body, seem to have very efficient repair systems. A possible explanation lies in the assumption that the expression of repair systems is controlled to various degrees in various differentiated tissues. In certain tumor cells (for example, in human breast cancer) repair seems to proceed at a greater rate than in normal cells from the same tissue, and this may explain the refractoriness of cancer cells to standard radiation and chemotherapy. At the present time we do not understand the cellular control mechanisms that are operative in relation to intracellular repair, however, the application of accelerated heavy ions can drastically reduce repair efficiency. This is illustrated in Fig. 11, where we compare the survival curves for x rays and high-LET neon ions. The RMR model has furnished a basis for classification of the types of injuries produced by various deleterious agents on the basis of the interaction between these injuries and the injuries produced by ionizing radiation. Table 1 is a simplified version of this classification scheme. The basis for the classification is the nature of the injury produced and whether or not one agent modifies the repair apparatus for injury by another agent. Usually one obtains information on possible synergisms by applying the two agents together to the small cell, either simultaneously or in sucession.

Table 1. Interaction of modalities.

INDEPENDENCE:	S (1,2) = S(1) • S(2), no interaction of lesions (U) or repair (r)
SIMPLE SYNERGISM:	U(1), U(2) additive same repair system (r)
COMPLEX SYNERGISM:	U(1) different from U(2) modality (1) affects r(2); modality (2) affects r(1) in an asymmetric manner
INTERACTIVE MODALITIES:	U(1) different from U(2) interaction in course of repair results in new U(3)

S = Survival
U = Lesion
r = Repair system

1 = Modality A
2 = Modality B
3 = Modality C

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IDEAS ON THE UNIFICATION OF RADIOBIOLOGICAL THEORIES

Stanley B. Curtis

A formulation of cell inactivation has been developed that incorporates several of the major ideas of past and present hypotheses of how individual mammalian cells are inactivated or rendered nonclonogenic by ionizing radiation. Elements from the repair-misrepair, lethal-potentially lethal, sublesion interaction, and tract structure models are combined to produce a single set of mutually compatible hypotheses. This unified model can be used to explain shoulders on survival curves, the exponential behavior both at low dose rates and at high LET, as well as to predict the kinetics of enzymatic cellular repair.

The basic elements of the unified model are:

1. Long-lived "sublesions" or "potentially lethal" lesions (half-lives of many minutes) are formed in the cell by the radiation field. The lesions can interact over large distances (micrometers) during the enzymatic repair process to form lethal lesions via "misrepair" processes. These can be identified with "intertract interactions" or "gamma kill," since they dominate at low LET. These lesions also have a finite probability for being repaired correctly.

2. One charged particle track can form lesions, some of which, depending on ionization density, may be created in such close proximity that *two or more* can interact strongly (i.e., in short times) to form lethal or irrepairable lesions. These can be identified with "intratrack interactions" or "ion kill," because they are caused by a single charged particle track.

3. The sublesions are produced by the very close proximity of several ionizations (perhaps as many as 6 to 10 are needed for each sublesion within a distance of 3 nm). The important physical parameters to describe the radiation field become the fluence of particles and the mean free path for creation of such "clusters" of ionizations along the track.

The chemical environment within the cell nucleus will determine whether a number of ionizations in close proximity will become a "potentially lethal" lesion, which the cell must deal with later via the enzymatic repair process.

Several consequences arising from this formulation are:

1. The most "fundamental" cellular survival data are obtained with non-dividing (stationary phase) cell cultures using either very low dose rates, or "delayed plating" procedures to allow maximum repair. From the former, values for the irrepairable component of damage can be obtained. Here, the long-range interaction of the sublesions can be neglected because the lesions can repair during the irradiation time and their concentration at any given time is small. The delayed plating experiments (at conventional dose rates) yield the amount of long-

range lesion interaction, which causes a shoulder on the survival curve. "Immediate plating" curves (even of stationary phase cultures) are more difficult to interpret since the fresh medium placed on the cells initiates the mitotic cycle and causes a "fixation" of damage before the cell has had a chance to complete the repair process. Thus, either interaction between a lesion and the chemical components of the medium, or "fixation points" within the cell cycle may cause repair inhibition and/or damage "fixation."

2. The survival curve at low LET only approximates a linear-quadratic expression. The parameter β has no fundamental significance. It varies with LET and goes to zero as LET increases. At *low LET*, the parameter α increases linearly with LET because it varies as const/($\overline{L_T}\lambda_I^2$), where $\overline{L_T}$ is the track-average LET and λ_I is the mean free path along the track between "sublesions." To the extent that λ_I is inversely proportional to ionization density (hence, to LET), α will increase linearly with LET.

3. The extrapolation number, n, of a low LET survival curve has no fundamental significance. The slope of the curve does, however, approach a constant at high dose. This limiting slope is a measure of the production rate (per unit dose) of the total number of lethal and "potentially lethal" lesions initially produced by the radiation.

This work was supported in part by a Senior International Fellowship (1-F06-TW00642-01) awarded by the Fogarty International Center of the National Institutes of Health and in part by the Office of Health and Environmental Resources of the U.S. Dept. of Energy under contract No. DE-AC03-76SF00098. The work was carried out during a 10-month Professional Research Leave, eight months visiting Prof. Wolfgang Pohlit at the Biophysics Institute, GSF, Frankfurt, West Germany, and two months visiting Herwig Paretzke, Institute of Radiation Protection GSF, Neuherberg, West Germany.

CELL AGE DISTRIBUTION IN MULTICELL TUMOR SPHEROIDS

Adrian Rodriguez, Edward L. Alpen, and Randy J. DeGuzman

During the past four years we have characterized the radiobiological response of multicell tumor spheroids (MTS) of a rat brain tumor cell line (9L). The studies have been done with x rays and accelerated heavy ions. We have shown that the radiation survival of MTS cells is enhanced compared to monolayer cells for low LET radiation.[1] With heavy-ion radiation the enhanced survival of MTS cells is reduced, and at an LET between 70–80 keV/μm there are no differences in survival between monolayer and MTS cells.[2] We have also observed that the RBE-LET relationship of MTS is similar to normal tissues.[3,4] Figure 1 shows the RBE-LET relationships for testes, gut, and MTS. There is a monotonic increase in RBE as the LET increases to 100 keV/μm. The highest RBE appears to be associated with an LET of around 100 keV/μm, which is lower than for monolayer cultured

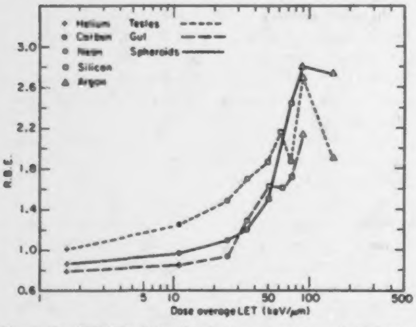

Fig. 1. The RBE-LET relationship for two mouse normal tissues (gut and testes) and multicell tumor spheroids. These data were obtained from plateau irradiation (0.0 cm water absorber) in heavy ion beams. *(XBL 829-4090)*

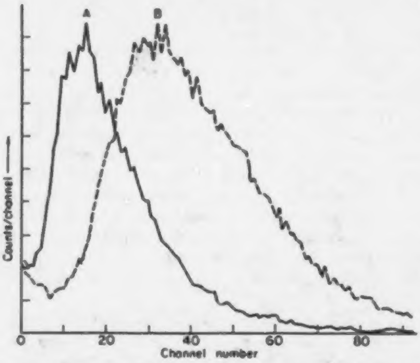

Fig. 2. Cell size distributions of MTS (A) and monolayers (B) determined with a Coulter counter and channelyzer. *(XBL 8212-4286)*

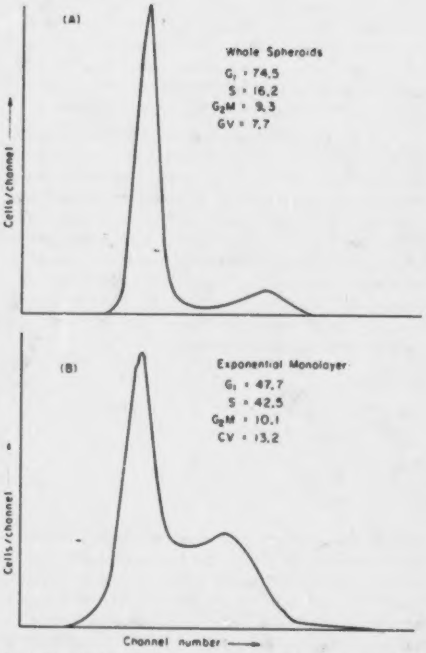

Fig. 3. DNA distributions of cells grown as (A) MTS and (B) exponentially growing monolayers. The MTS cells were derived from whole spheroids that were completely dispersed. Channel number is proportional to DNA content. *(XBL 8212-4288)*

cells.[5] These data were determined for well defined LET distributions in the plateau regions of ionization of accelerated heavy ions.

We are presently characterizing 9L MTS with respect to cell age distribution and growth conditions. We have made preliminary observations on cell age distribution and cell size in MTS compared to monolayer cells. Cells from MTS are smaller in size than monolayer cells (Fig. 2). The difference in cell size can be attributed to alterations in the cytoskeleton due to the physical constraints of being closely packed together and to a large fraction of the cell population being in G_1 or G_0 phase of the cell cycle.

On fixed and stained cross sections of MTS we have observed that there are three distinct regions. There is a central core region of necrosis surrounded by a rim of viable cells. The rim of viable cells can be subdivided into an outer proliferating region with many mitoses and an inner nonproliferating region with few mitoses. Labeling experiments with ^{3}H-thymidine have determined that the growth fraction for spheroids greater than 400μm in diameter is about 40%. Comparison of DNA histogram of monolayer and MTS cells by flow cytofluorimetry (FACS IV, Becton-Dickinson) indicates, as shown in Fig. 3, that the cell population of MTS is primarily G_1 with few S and G_2M cells. Exponential growing monolayers have more S cells.

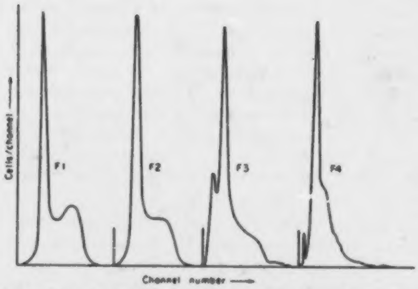

Fig. 4. DNA distributions of cells sequentially dispersed from MTS (500 um in diameter). F_1 - F_4 represents fractions of cells from the surface of the MTS to the necrotic core. *(XBL 8212-4287)*

Sequentially dispersed layers of cells from MTS have been analyzed by flow cytofluorimetry as is shown in Fig. 4. Each fraction of cells (F_1-F_4) represents a deeper layer of cells in the spheroid. Fraction 1 (F_1), the outer cell layer, is representative of an exponentially growing population as shown for monolayer cells in Fig. 3. Fractions F_2 and F_3 show an increasing population of G_1 or G_0 cells with fewer G_2M and S phase cells. These cells are either cycling slowly or, more likely, are arrested in G_1. The prominent peak in fraction 4 represents dead cells and debris in the necrotic core and is characterized by a peak channel lower than the G_1 peak in the previous fractions of cells.

These studies indicate that spheroids are similar to growing solid tumors and tissues with respect to cell age distribution and the presence of necrotic regions. The spheroids thus afford a unique model system for tissue and tumor radiobiological responses. The various populations of cycling and noncycling cells in MTS can be readily isolated and examined independently in the hope that these studies will shed light on the mechanisms of radioresistance of cells grown as MTS. Future studies will not only involve characterization of the radiation survival of these populations but also the radiation repair capacity.

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INDUCTION OF HARDERIAN GLAND TUMORS IN MICE BY HEAVY ION IRRADIATION

Edward L. Alpen, Patricia Powers-Risius, R.J. Michael Fry,* E. John Ainsworth, Randy J. DeGuzman, Linda D. Harrison, and Virginia C. Havens

This project was undertaken as part of the program to evaluate the biological effects of charged particle beams generated by the LBL Bevelac and 184-Inch Synchrocyclotron. Experiments have been designed to investigate the relationship of LET to the effectiveness of radiation of different qualities to induce tumors; and to study the factors that may influence the shape of the dose-response curve for cancer induction by high-LET radiation. We have chosen as a model tumor system the Harderian gland in mice. Although the total number of cells in these glands is small and the natural incidence is low (~2.7%) they are reasonably susceptible to the induction of tumors by irradiation. Fry et al.[1] observed that Harderian gland cells initiated by radiation could be promoted with elevated protactin levels provided by pituitary isografts, leading to increased tumor incidence in hormone treated animals. About two weeks prior to irradiation, pituitaries from B_6CF_1/ANL mice are put under the capsule of the spleen of 100 day old syngeneic recipients. Figure 1 illustrates the time sequence of our procedure. The transplanted isografts are not under the normal control of the hormones released by the hypothalamus into the portal system of the hypophysis; the transplanted pituitaries grow and release prolactin, raising the concentration of this hormone above normal blood levels (unpublished work, this laboratory, Clemens and Garcia). The elevated prolactin levels increase the amount of mammary tissue, the normal target for this hormone, and the identification of mammary gland hyperplasia at the completion of the experiment is a simple and reliable indicator of the activity of the isografts. The use of pituitary isografts has two advantages. Firstly, the tumors appear earlier than without the isografts, thus shortening the length of the experiment and secondly, the elevated prolactin level appears to maximize the expression of induced lesions, thus increasing the response and reducing the number of mice required to obtain significant increase in tumor numbers above the normal incidence. If, as we assume, the pituitary isografts maximize the expression of the transformed cells, then the dose-response curves obtained under these ex-

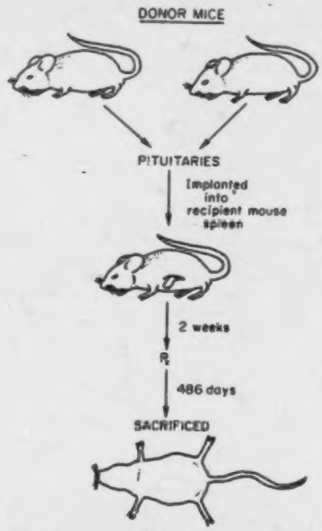

Fig. 1. Schematic of pituitary implant procedure. Two pituitaries from B_6CF_1/ANL mice are injected into the spleen of 100 day old syngeneic female recipients. About 2 weeks later the implanted mice are irradiated: 16 months later they are sacrificed. *(XBL 815-3811)*

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perimental conditions should reflect the dose-response relationships for initiation of the cancer process. It is the comparative effectiveness of the various heavy-ion beams for initiation that is of particular interest. A further advantage of this model tumor system is that we have data for tumor incidences following exposure to different energy neutrons at the JANUS reactor and the FERMI facilities.[2]

The relative effectiveness of cobalt gamma radiation is being compared to helium, carbon, neon, argon, and iron ions, representing an LET range of <1 keV/μm for ^{60}Co to 650 keV/μm for argon ions. Figure 2 shows the Bragg curves for the beams we used; the arrows indicate the position at which the mouse was irradiated in the spread Bragg peak. Because of the low dose rate of the iron beam the plateau region of the unmodified iron beam was used.

Table 1 lists the total number of animals committed to this study to date. Not all groups have reached the appropriate time for sacrifice. Since we use prevalence of tumors as the endpoint, the mice are sacrificed at a fixed time, 16 ± 0.5 months after irradiation. The Harderian glands are removed, histologically processed, and the number of tumors are counted microscopically. Since this work is still in progress, with some animal sacrifices yet to be completed and much histological scoring to be done, it is premature to describe in detail the analysis of the data. The final prevalence value will be based on the percent of mice with active isografts accounted for at sacrifice that have microscopically confirmed Harderian tumors.

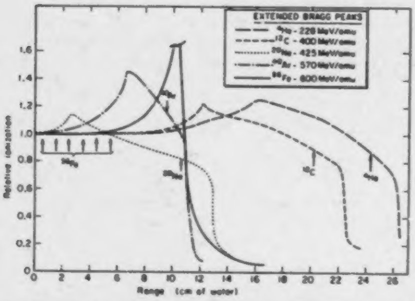

Fig. 2. Depth-dose distributions for the ion beams used in this study. The irradiation positions in the spread Bragg peaks are indicated by the arrows for all the ions except ^{56}Fe. In the case of ^{56}Fe the arrows indicate the plateau region, which was the part of the beam used. The estimates of the dose-average LET values were ^{4}He: 6 keV/μm; ^{12}C: 80 keV/μm; ^{20}Ne: 150 keV/μm; ^{56}Fe: 180 keV/μm; and ^{40}Ar: 650 keV/μm. (LET values were obtained from a computer calculation developed by Stan B. Curtis, LBL.) *(XBL 815-3797)*

The preliminary data obtained so far are shown in Fig. 3. It can be seen that there is a general trend of an increase in the initial slopes of the curves with increasing LET. The curves for carbon, neon, argon, and iron all show the bending over at relatively low doses. Since the dose-averaged LET for the argon beam is well above 100 keV/μm (about 650 keV/μm) the finding of very steep initial slope for the tumor prevalence as a function of ^{40}Ar dose is perhaps at variance with predictions. If the RBE for carcinogenesis in relation to LET behaved similarly

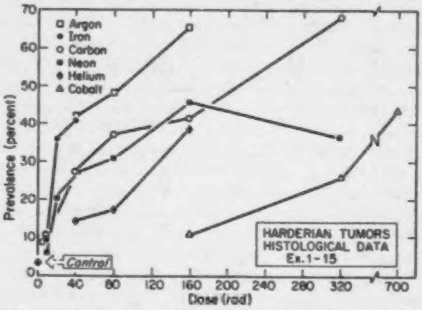

Fig. 3. Prevalence of Harderian gland tumors as a function of dose for the irradiations indicated. The estimated LET values are given in the caption for Fig. 2. *(XBL 825-3811)*

*Table 1. Number of mice committed to study groups.**

	Dose(rad)								
	5	10	15	20	40	80	160	320	700
^{60}Co	—	—	—	—	189	182	180	181	90
Helium	—	—	—	—	201	203	200	210	40
Carbon	144	100	—	—	194	112	109	63	—
Neon	226	191	97	195	121	144	111	65	—
Argon	—	—	—	—	102	74	74	—	—
Iron	6	24	—	24	25	—	—	—	—

** Unirradiated implant controls: 250*

to mutation and cell killing we would expect some decrease in RBE at very high LET values. The data are not sufficiently precise to delineate the RBE-LET relationship, but it is possible that the RBE value may plateau rather than peak at LET values of 100 keV/μm or greater. The marked effectiveness of the ^{56}Fe beam in producing tumors is of interest. We have noted that irradiation with this beam produces multiple tumors in the individual Harderian glands and in both glands with a higher frequency than with any other of the beams. The interactions of ^{56}Fe ions with tissue elements are complex and the LET value for such a beam may be misleading. However, it is clear that further investigations of the carcinogenic effects of this heavy ion would be productive.

The spread Bragg peaks are not homogenous beams with respect to LET spectra, and are less suitable than the plateau region of the beam for biological experiments. It may now be possible to obtain the appropriate range of LET values with the plateau regions of the beams for future experiments. It has been noted that for cell killing in mouse tissues the variation in radiation response between heavy ions cannot be accounted for on the basis of differences in LET alone and that the particle mass or charge is important.[3,4] We must conclude that heavy ions have a high carcinogenic potential in the B_6CF_1/ANL mouse Harderian gland promoted with pituitary implants.

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CATARACT PRODUCTION IN MICE BY FRACTIONATED DOSES OF ^{12}C PARTICLES OR ^{60}CO GAMMA RADIATION

E.J. Ainsworth and J.G. Jose

We have reported previously on the murine cataract response following exposure to 225 kVp x-rays, and ^{12}C, ^{20}Ne, and ^{40}Ar ions under circumstances in which animals received upper body exposures, and in the case of charged particles, were irradiated in the plateau portion of the Bragg curve.[1,2] Our results were compared with data reported earlier by others who exposed animals to photons or various neutron energies to explore relationships between relative biological effectiveness (RBE) and linear energy transfer (LET). While considerable information exists concerning the murine cataract response to single doses of photons or high LET radiations, relationships between RBE and LET are not yet defined fully, and a dearth of information exists concerning the extent to which cataract risk is reduced when doses of high or low LET radiations are fractionated. Bond et al. have reported no sparing effects when paired doses of high LET neutrons are given; whereas, cataractogenic hazard is reduced significantly when paired doses of photons are given.[3] The objective of our study was to evaluate the sparing effects of long-term dose fractionation with high LET ^{12}C ions and ^{60}Co gamma radiation.

Because cataract examinations could be performed nondestructively, mice dedicated to studies of life shortening and carcinogenic response to photons and heavy charged particles were available for study. The project's staffing was such that slit-lamp biomicroscopic examinations could be performed only on $CB6F_1$ male mice that received single or fractionated doses of 225 MeV/amu ^{12}C ions (0.4, 0.8, and 1.2 Gy) and animals that received a single or fractionated dose of ^{60}Co gamma radiation of 4.17 Gy. A total of 24 fractionated doses were administered weekly. Using a semiquantitative scoring system described elsewhere,[1] the severity of cataract response was evaluated at three sample times following the single dose or first fractionated dose.

Figure 1 summarizes the results obtained with unirradiated controls, and mice that received total doses of 1.2 ^{12}C rad or 4.17 gamma rad as a single dose or in 24 weekly fractions. The most important feature of this figure is that fractionation of the ^{12}C ion dose produces no reduction of cataract response, whereas, fractionation of the gamma radiation dose produced a marked sparing effect, especially at the first two sample times. A very important aspect of these results is the increase in cataract score at the third sample time in animals that received fractionated gamma doses. Clearly, inferences pertaining to the sparing effects of gamma radiation would be in-

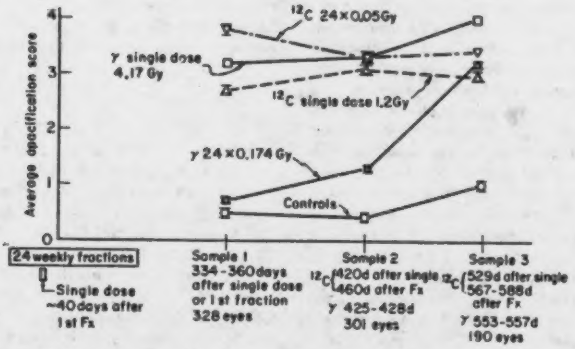

Fig. 1. Average opacification scores (cataract incidence) comparing unirradiated control mice with mice that received total doses of 1.2 ^{12}C rad or 4.17 gamma rad either as a single dose or in 24 weekly fractions. (XBL 824-3736)

fluenced drastically by the time after irradiation at which the evaluations were made, and the same would be true for estimates of RBE under conditions of dose fractionation. Fractionation of the ^{12}C ion dose resulted in a significantly higher cataract score than did the same total single dose at the first sample time, but this result was not confirmed at the subsequent samples.

Comparison of the effect of ^{12}C ions and ^{60}Co gamma radiation on time of cataract expression (latency) is an important consideration after both single or fractionated doses. Over the time span of this study, cataract scores among animals that received single or fractionated doses of ^{12}C ions showed no time-dependent increase. In contrast, marked time dependent increase was observed among animals that received fractionated gamma doses, and the increase in cataract score from approximately 3.0 to 4.0 among animals that received a single dose is probably significant. We conclude that important latency differences exist, and as mentioned above, estimates of cataractogenic hazard in RBE can be influenced materially. Risk assessment considerations emphasize the effects of fractionated exposures or doses received continuously at very low dose rates. Present results from animals that received fractionated exposures indicate that estimates of RBE would decrease as the time at which cataract examinations are conducted is extended. For example, a mimimum estimate is of the order of 3.5 based on data collected at sample 3; whereas, much higher RBE would be inferred from results collected at sample 1. The single dose results are consistent with an RBE estimate of 3.5 or less at all sample times. Because a broad range of responses (and doses) is needed to confidently estimate RBE, estimates rendered here based on comparisons between single doses are considered preliminary.

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RESPONSE OF MOUSE MARROW COLONY FORMING UNITS (CFU-S) TO HEAVY CHARGED PARTICLES

E. John Ainsworth, Lynn J. Mahlmann, and John C. Prioleau

A fundamental objective of the Bevalac Biomedical Program is to characterize biological responses in relation to the physical properties of heavy charged particles. Information collected with a variety of biological systems should contribute to the exploitation of the unique properties of heavy charged particles for radiotherapy and other medical applications. Definition of relationships between relative biological effectiveness (RBE) and linear energy transfer (LET) have been pursued using various *in vitro* and *in vivo* model systems. Prior work has shown that the maximum RBE occurs at a higher level of dose-averaged LET for several *in vitro* systems than is the case for certain *in vivo* model systems, and that a significant effect of particle mass/charge exist, independent of estimated dose-averaged LET.[1] The bone marrow transplantation methods developed by Till and McCullough provides a highly suitable *in vivo* model system to evaluate cell killing, repair of radiation injury and proliferation, and definition of how homeostasis is perturbed on a sustained basis and manifested as a persistent late effect of radiation.

Relationships between RBE for CFU-S killing and LET were the first questions addressed in our studies. The procedure used was to harvest bone marrow from the femurs of animals within two hours after total-body irradiation, preparation of appropriate aliquots, and injection of marrow suspensions into animals that had received a supralethal dose of ^{60}Co gamma radiation. Recipients of bone marrow transplants are sacrificed at 8–10 days, spleens excised and placed in an appropriate fixitive, and spleen colonies greater than 0.5 mm accounted with a dissecting microscope. Survival curves are fitted utilizing a program developed by Dr. E. L. Alpen, and in cases where CFU-S content for femur was the information sought, averaged CFU-S content is computed by routine statistical methods. Details of these procedures are described elsewhere.[2]

Figure 1 summarizes the available data on RBE-LET relationships for CFU-S killing. As the figure legend indicates, two strains of mice, the LAF$_1$ and CB6F$_1$, have been used, and studies have been performed both in the plateau portion of the Bragg curve and under circumstances where the Bragg curve has been spread to dimension of 4 cm using a spiral ridge filter. Two data points in Fig. 1 were obtained by irradiation of bone marrow cell suspensions *in vitro*. The maximum RBE at 10% survival observed, 2.1 for plateau argon ions, was obtained using an *in vitro* procedure. The RBE$_{10}$ estimate for plateau argon ions at 100 keV/μm is from a single experiment, and is being reevaluated using *in vivo* irradiation procedures. The results in Fig. 1 are consistent with a maximum RBE at 80–100 keV/μm, as has been observed previously for testes weight loss and intestinal microcolony responses.[3,4] The present data are not yet sufficient to ascertain the importance of mass/charge, independent of LET for CFU-S RBE. We plan to collect more data with ^{40}Ar, ^{28}Si, ^{20}Ne, and ^{56}Fe accelerated to various energies to define RBE-LET relationships and identify any effects of mass/charge independent of LET over an LET range of approximately 10–200 keV/μm. All future studies will emphasize irradiations performed in the plateau portion of the Bragg curve.

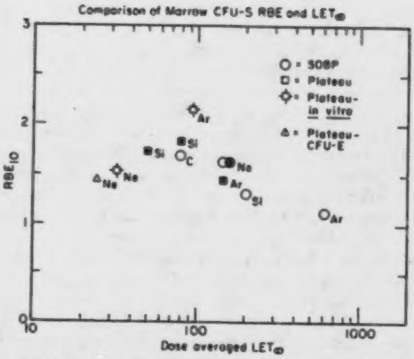

Fig. 1. Relationships between RBE at 10% survival for CFU-S and dose-averaged LET. Solid symbols indicate results from CB6F$_1$ mice and open symbols indicate results from LAF$_1$ mice. For comparisons, unpublished results of CFU-E from Alpen et al. are shown in the figure. *(XBL 8212-4299)*

Two of the data points presented in Fig. 1 are for ^{28}Si ions where irradiations were performed either in the plateau portion of the Bragg curve or in the distal 4 cm of a Bragg peak spread to 12 cm using a spiral ridge filter. This comparison was made in support of the potential use of ^{28}Si ions for radiotherapy, and the question addressed was the RBE$_{10}$ at various positions in Bragg curve. Previous preliminary results obtained for the killing of intestinal microcolonies indicated the RBE was higher in the plateau portion of the Bragg curve than in the spread Bragg peak (personal communications, Drs. L. Goldstein and E. L. Alpen). Fig. 2 shows results from replicated experiments where D_0 in plateau portion of the Bragg curve is significantly lower than in the distal peak. The RBE estimates shown in Fig. 2 are considered preliminary because more data are being added currently to the survival curve for ^{60}Co gamma radiation.

Biological responses to fractionated exposure are an important fundamental question and also have applicability to the radiotherapeutic applications of ionizing radiations. The CFU-S has only a meager capacity to repair sublethal damage following photon-irradiation, and other *in vivo* model systems are better suited to address questions of SLD repair. However, the CFU-S is a model system well suited to explore the effects of daily fractionation on femur CFU-S content and on repopulation following completion of a course of fractionated exposures. When fractionated exposures are given, the CFU-S content is influenced by any repair of SLD, repair of potentially-lethal damage (PLD), any proliferation that occurs in the CFU-S compartment, and the relative allocation of CFU-S either to the stem cell compartment or to the differentiating compartments. When doses of photons and HZE particles are selected to produce the same cell killing per dose fraction, the hypothesis is that femur CFU-S content should be the same if there are no important LET dependence effects on SLD, PLD, or the initiation of proliferation. Moreover, if residual lesions in surviving stem cells are either absent or are the same, and if damage to hematopoietic control systems is also the same, femoral repopulation should proceed on a similar temporal basis. We observed previously that nine fractionated doses of fission-spectrum neutrons from the JANUS Reactor produced greater CFU-S depression/femur than did nine fractionated gamma doses under circumstances where the dose/fraction was calculated to produce equal CFU-S killing per fraction.[5] Additionally, CFU-S repopulation proceeded more rapidly during the first 7–9 days following gamma radiation than was the case following completion of the nine-fraction neutron sequence. Those results indicated an effect of fission neutrons on PLD repair and/or the onset of proliferation that accounted for the higher RBE during a course of fractionated exposure, and the delay in onset of proliferation following completion of fractionated exposures was consistent with the same interpretation.

We have initiated similar studies with CB6F$_1$ mice irradiated with 670-MeV ^{20}Ne ions and ^{60}Co gamma radiation because the CFU-S methodology is eminently suited to test specific hypothesis pertaining to accumulation of damage and repopulation under conditions with dose fractionation. CB6F$_1$ mice received total doses of 5.76 ^{20}Ne Gy or 9.04 ^{60}Co gamma Gy in eight fractions over two weeks. The daily fractions of 0.72 and 1.13 Gy reflect the RBE for CFU-S killing inferred from single dose CFU-S survival curves. The results in Fig. 3 indicate no delay in onset of CFU-S proliferation among animals that received fractionated doses of ^{20}Ne, and in fact, the femur CFU-S content was depressed to a greater extent (9 CFU-S per femur) for ^{60}Co gamma radiation than was the case for the fractionation sequence with ^{20}Ne ions (60 CFU-S/femur). The statistically significant excess killing produced by fractionated doses of gamma radiation probably indicates that our RBE for ^{20}Ne ions was slightly underestimated, but that underestimate is doubtless well within the 95% confidence limits of the D_0 estimate. Although the ^{20}Ne irradiated animals had a significantly increased CFU-S content per femur during the first week after irradiation, this advantage disappeared during the third week when the CFU-S content of gamma irradiated animals was significantly higher. More information is being collected on CFU-S repopulation after 10 days, and if the present trend shown in Fig. 3 is maintained, we will infer an LET dependence on the second phase of CFU-S repopulation following fractionated exposures. The hypotheses that all subsequent repopulation phenomena should be the same and that animals that experienced less CFU-S depression following fractionated doses of neon irradiation should enjoy the advantages of an earlier repopulation are not confirmed. When a definitive data set with ^{20}Ne ions is obtained we will proceed with further studies using fractionated doses of ^{40}Ar or ^{28}Si ions that are characterized by a higher RBE$_{10}$ for cell killing than is the case for ^{20}Ne ions.

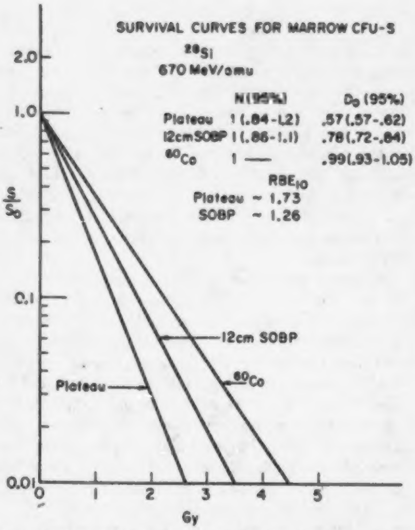

Fig. 2. CFU-S survival in femoral marrow of CB6F$_1$ female mice exposed to 670 MeV/amu ^{28}Si in the plateau or in the distal 4 cm of a Bragg peak spread to 12 cm. Also shown is the comparable survival curve for ^{60}Co gamma radiation. (XBL 8211-4219)

Biological systems are remarkably endowed with the capacity to reestablish a "normal steady state" following damage produced by ionizing radiations or other physical-chemical agents. Processes by which homeostasis are reestablished and long term perturbations or adjustments in homeostasis are poorly understood. Our prior studies were the first to demonstrate convincingly a significant decrease in the CFU-S content in femurs of age-irradiated mice.[6] Neither the mechanism nor the functional significance of this alteration in bone marrow CFU-S content is understood, and further work in this area will be rewarding. Our prior studies have demonstrated no dependence of LET on this late effect, other than for cell killing, and ongoing work in this area will be confined to photon-irradiated animals until a rationale for studies with heavy charged particles emerges. Pilot studies have been done in our laboratory and in collaboration with

Drs. David A. Crouse at the University of Nebraska Medical School and Michael Hagen at the Armed Forces Radiobiology Research Institute. Limited data have been collected from mice that received whole-body exposures to 670-MeV ^{20}Ne particles and the results show a significant decrease in CFU-S content at 19 months after irradiation. This result is not unexpected based on our prior studies with photon and fission-neutron irradiated animals.

A more interesting result comes from studies conducted on survivors of studies in which acute skin responses (flank skin) were evaluated in Balb/c mice given single or fractionated doses to a significant portion of the right leg, including approximately half of the femur and the tibia-fibula. The original rationale for these studies were to assess the extent to which comparatively high locally applied doses of x-irradiation influence the femoral stroma and could thereby affect the extent to which CFU-S surviving in the irradiated femur could repopulate, or the irradiated femur could be reseeded from other sources such as CFU-S present in the blood. Part of the motivation for this study came from peripheral hematological results from a prior associate who had received partial body radiotherapy following a mastectomy and showed a persistent anemia and thrombocytopenia for more than 1 year after the irradiation (E. J. Ainsworth and M. Miller, unpublished observations, 1975). Subsequently, Werts *et al.* published results on alterations in erythropoiesis and the induction of extramedullary hematopoiesis induced in mice following the administration of high single photon doses to one leg.[7] Their results clearly demonstrated a significant systemic response to single-leg irradiation, but no information on response of CFU-S was reported. We have found a significant and sustained systemic response to right-leg only irradiation that influences the CFU-S content in the contralateral (unirradiated) femur. The results in Fig. 4 show a significantly reduced CFU-S content in the femurs of both the irradiated and unirradiated leg, in comparison with aged unirradiated control animals at 14 months after local x-irradiation. The most interesting and potentially important aspect of these observations is to study the mechanisms whereby systemic responses are produced. Pursuant to this, *in vitro* culture procedures are being used by Drs. Crouse and Hagen to evaluate alterations in stromal elements and changes in cycle kinetics of CFU-S. Because the entire femur was

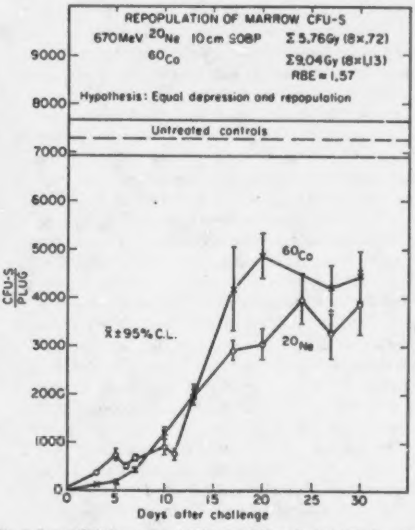

Fig. 3. Femur CFU-S content and 95% confidence limits in CB6F, male mice given eight fractionated doses of ^{60}Co gamma radiation or ^{20}Ne ions in the distal 4 cm of a spread Bragg peak. *(XBL 8211-4213)*

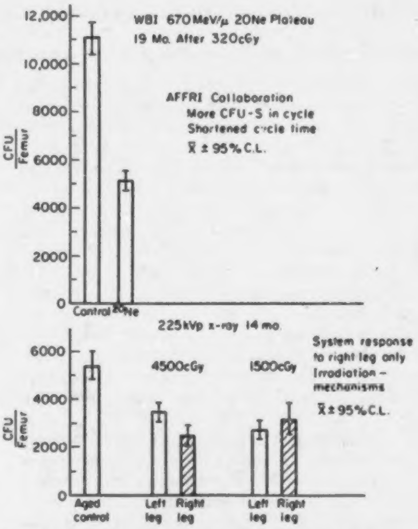

Fig. 4. Late effects on marrow CFU-S content. Top Panel: Femur CFU-S content in CB6F, male mice at 19 months after a total body dose of 320 Gy of ^{20}Ne ions. Mice were exposed in the plateau portion of the Bragg curve. Bottom Panel: Femoral CFU-S content in Balb/c female mice in which the right leg was irradiated with 225 kVp x rays 14 months previously. *(XBL 8211-4220)*

not irradiated in Balb/c animals involved in the skin tolerance studies, the estimates of CFU-S content per femur are considered conservative. Our future studies will concentrate on demonstration and isolation of humoral factors that may be involved in effecting the sustained reduction in the size of the CFU-S repopulation in locally irradiated animals. We conclude that the sustained late damage to the stroma and humoral factors influencing hematopoietic control systems may be involved.

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LIFE-SHORTENING EFFECTS OF HEAVY CHARGED PARTICLES: A STATUS REPORT

E. John Ainsworth, John C. Prioleau, and Lynn J. Mahlmann

The purpose of this project is to test hypotheses on relationships between relative biological effectiveness (RBE) for life span shortening and linear energy transfer (LET). The approach is to determine the RBE for life shortening over a broad range of estimated dose-averaged LETs. Data collected from this pilot project using comparatively high doses will permit inferences concerning RBE-LET relationships for life shortening, and potentially, for tumorigenesis, in comparison with RBE-LET relationships for other short-term endpoints such as cell killing. Pathology support is being provided for this project by Dr. Lizbeth Kraft of the NASA-Ames Laboratory, and the life-shortening/tumorigenesis data from this project will be critical for the design of future low dose experiments with much larger samples of mice, where the objective is to define shapes of dose-response curves for various tumors.

The fundamental question concerns the most appropriate RBE or quality factor to be used for assessment of carcinogenic risk following exposure to heavy charged particles characterized by different LETs. Whereas an RBE estimate for life shortening, or dose-response relationships defined for life shortening, do not provide estimates of RBE for induction/promotion of various tumors or described shapes of dose-response curves for specific tumors, RBE estimate for life shortening may provide boundary condition estimates of RBE for tumorigenesis. It is felt that at low doses, much of the life shortening is attributable to induction/promotion of neoplastic diseases. Consequently, if the RBE estimate for life shortening is 10–20, that RBE obtains for whatever disease processes are responsible for life shortening. Phenomena now associated with high-LET tumorigenesis, namely a nonlinear dose-response curve, and an enhancement phenomenon associated with at least an earlier appearance time of some tumors when doses of high-LET doses are fractionated were first described for life-shortening response.[1,2] Data forthcoming from this project compliment studies on Harderian gland carcinogenesis, and they should assist with the development of predictive models (none exist currently) for carcinogenic hazard following exposure to high-LET radiation over a range of LETs. The Bevalac is eminently well suited for these studies because of the broad range of dose-averaged LETs obtained in the plateau portion of the Bragg curve where the range of LETs is narrow and inferences about RBE-LET relationships can be drawn confidently.

The approach and current status of our project is shown in Table 1. The animals used are male Balb/c x C57/b1$_6$ (CB6F$_1$), a reciprocal hybrid of the mouse strain used in large-scale studies of life shortening in tumorigenesis following exposure to fission-spectrum neutrons or ^{60}Co gamma radiation.[1,3] The original approach was to expose mice to graded doses of heavy charged particle

Table 1. Skyhook status update – Sept. 27, 1982.

Radiation	Est. LET keV/μm	No. of replicates	No. irradiations completed	Total irradiations planned	No. of exits	No. alive	No. needed to comp.	Days at risk Min.	Days at risk Max.
^{12}C 225 MeV/amu (4cm SOBP)	~ 80								
Single Dose		4	354	330	312	42	0	69	942
Controls		2	33	50	31	2	0	–	942
24 Weekly Fractions		1	346	330	346	0	0	–	1169
Controls		1	53	50	53	0	0	–	1166
Single Dose + ^{60}Co γ		2	76	150	72	4	74	941	1187
Controls		2	32	30	32	0	0	–	1106
^{60}Coγ	> 1								
Single Dose		5	316	330	316	0	14	–	1185
Controls		4	50	50	50	0	0	–	1091
24 Weekly Fractions		3	265	330	265	0	65	–	1217
Controls		2	58	50	57	0	0	nd	1116
^{20}Ne 557/670 MeV/amu (Plateau)	~ 30								
Single Dose		5	525	330	138	387	0	88	1033
Controls		4	74	50	9	43	0	88	537
^{20}Ne 557 MeV/amu (4 cm SOBP)	~130								
Single Dose		3	320	330	192	128	10	537	1032
Controls		3	57	50	25	32	0	537	1032
^{28}Si 320 MeV/amu (Plateau)	~ 80								
Single Dose		3	360	330	24	336	0	109	453
Controls		2	70	50	1	59	0	109	453
^{40}Ar 330 MeV/amu (Plateau)	~140								
Single Dose		1	78	330	0	78	252	–	87
Controls		1	10	50	0	10	40	–	87

(0.40–3.20 Gy) or ^{60}Co gamma rays (2.68–7.88 Gy) using groups of 50 animals/dose (including zero dose) at all levels except the lowest dose where the sample size programmed was 80 mice. The same sample sizes were used to evaluate the effects of weekly dose fractionation for 225 MeV/amu ^{12}C particle and ^{60}Co gamma radiation where the weekly dose ranges were 1.6 to 13.3 rad and 17.3 to 79 rad, respectively. One hypothesis tested was that 225 MeV ^{12}C ions characterized by an estimated LET of 80 keV/m would be equally effective as fission-spectrum neutrons for production of life shortening. The estimated LET for fission neutrons from the JANUS reactor is in the same range.[4] Although not all animals exposed to single doses of 225 MeV/amu ^{12}C ions are dead, the results available at this time indicate that this hypothesis is not confirmed. Data current in hand indicate that ^{12}C ions are appreciably less effective than are fission-spectrum neutrons for production of life shortening, but as is the case for fission-spectrum neutrons, dose fractionation produces no sparing effect on life shortening (Fig. 1).

Although it was felt initially that sample sizes in the range of 50–80/group would be adequate for this pilot study, the lower than expected effectiveness of ^{12}C ions produced results where no significant life shortening was produced at doses less than 126 to 160 rad, and in some cases mean survival time varied independently of dose. The doses selected for this study, based on the hypothesis stated above, had been found to be "too close together"

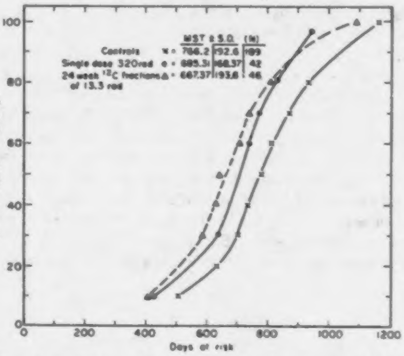

Fig. 1. Cumulative mortality in CB$_6$F$_1$ male mice given single or 24 weekly fractionated doses of 225-MeV ^{12}C ions. Mice were exposed in the approximate center of a 4-cm spread Bragg peak.

(XBL 8212-4300)

and the range of doses explored has been extended by 5.0 Gy to define more accurately the effectiveness of 225 MeV ^{12}C particles for production of life shortening. We are conferring with our statistical consultant, Mr. Sylvanus Tyler, about the relative advantages of decreasing the number of radiation doses and increasing the sample sizes for any subsequent replications. Sample sizes in the range of 100 animals/dose should yield more accurate estimates of dose-response relationships for life shortening and could provide far more significant information regarding tumor responses than would be obtained based on the current sample sizes.

The range of LET explored for heavy charged particles is from ~30 keV/μm for plateau 557/670 MeV/amu ^{20}Ne ions to ~140 keV/μm for 330 MeV/amu ^{40}Ar ions. Our early single dose studies with ^{12}C and ^{20}Ne ions involved the use of Bragg peaks extended to 4 cm by use of spiral ridge filters, but more recent studies have involved the use of the plateau portions of Bragg curves to obtain a more narrow range of estimated LET. Because data available currently indicate that LET alone does not predict the cell killing response to heavy charged particles and, at least at high levels of LET, an effect of mass/charge independent of LET exists, animals have been exposed in the plateau portion of the Bragg curve to 320 MeV/amu ^{28}Si ions characterized by a dose-averaged LET (80 keV/m) similar to that estimated for 325 MeV ^{12}C particles for animals where exposed in a 4-cm spread Bragg peak. Another hypothesis tested concerns the independence of radiation damage produced by heavy charged particles and photons for production of life shortening. Earlier studies have demonstrated a lack of total independence, over short time frames of a few hours, for cell killing when a photon dose was given shortly after a dose of high-LET ^{20}Ne ions. We elected to test the hypothesis of independence by administering first a ^{12}C dose of 40 rad followed by a single gamma dose of 268 rad where the gamma dose was given within 1–2 hours of the ^{12}C dose. The results available to date are not sufficient for conclusions to be drawn, but because of the less than expected life shortening for ^{12}C ions, we doubt that the experiment, as designed, would permit detection of an interaction term. Under consideration is the matter of testing the hypothesis of damaged interactions using a higher LET particle than ^{12}C ions where animals are exposed in the plateau portion of the Bragg curve; plateau ^{28}Si (320 MeV/amu) or plateau ^{40}Ar (330 MeV/amu) are candidate particles. The damage interaction question is an important one in the sense of complex radiation fields in which personnel are exposed both in terrestrial and space radiation environments. During 1983 the plan is to extend the range of LETs to which animals are exposed to ~180–200 keV/m using high energy ^{56}Fe ions. Because of the absence of a sparing effect of dose fractionation with ^{12}C ions where the RBE for life shortening is lower than expected, consideration is currently being given to the initiation of dose fractionation studies with plateau 670 MeV ^{20}Ne ions to determine the extent to which there is a sparing effect on life shortening and carcinogenic response curves. That decision will be deferred until life shortening results from animals given single doses of ^{20}Ne ions are adequate to provide at least preliminary estimates of the life shortening effect.

The contribution of Mr. Andy Shih and Ms. Louise Chere to these studies is gratefully acknowledged.

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TREATMENT OF CANCER WITH HEAVY CHARGED PARTICLES

Joseph R. Castro, William M. Saunders, George T. Y. Chen, Cornelius A. Tobias, J. Michael Collier, Samuel Pitluck, Kay A. Woodruff, Ranu Grewal-Bahl,* Theodore L. Phillips, Aude Cartigny, Todd Richards, William Dedo, Jacquelyn St. John, and Robert E. Walton†

This project has been granted continuing National Cancer Institute support from July 1982 through July 1987, which together with DOE support should permit continued exploration of the role of heavy charged particles in clinical cancer care. The Northern California Oncology Group and the Radiation Therapy Oncology group together with the Bay Area Heavy Ion Association will continue to provide support for protocol design and implementation, patient referral, data collection and analysis, and statistical services for the clinical trial. Continued patient accrual during the past year has included irradiation with helium ions at the 184-Inch Cyclotron (342 patients) and irradiation with heavy particles at the Bevalac (119 patients).

Since 1975 461 patients have been irradiated with particles and 30 patients irradiated as controls in randomized studies (Table 1).

Current protocols are ongoing for the following tumor sites:

Description	Protocol No.
1. Localized squamous cell carcinoma of the esophagus, nonrandomized. (helium and heavy ions)	LBL-NCOG 3E81/RTOG 79-09
2. Localized ocular melanoma, nonrandomized (helium)	LBL-NCOG 7081/RTOG 79-08
3. Phase I—Phase II Study of miscellaneous locally advanced tumors, nonrandomized. (helium and heavy ions)	LBL-NCOG 0R81/RTOG 79-11
4. Localized unresectable carcinoma of the pancreas, nonrandomized. (helium and heavy ions)	LBL-VASOG

PRECISION HIGH DOSE RADIOTHERAPY WITH HELIUM ION RADIOTHERAPY (184-INCH CYCLOTRON)

During the past year we have continued our studies of helium-ion precision radiation therapy in ocular tumors, and tumors close to the spinal cord and base of brain in order to test the potential clinical advantage of improved dose localization. Our observation is that for tumors adjacent to critical organs such as these we are able to deliver a higher dose to the tumor with helium-ion radiotherapy than can be delivered with standard megavoltage irradiation, while keeping doses to normal tissues at acceptable levels. These tumors often present a severe problem for radiotherapy because the doses required for successful control of a tumor exceed the tolerance of critical nearby structures, as in the central nervous system. With charged-particle radiotherapy the physical characteristics of the beam permit doses of 60 to 75 GyE to be delivered successfully to the tumor target while keeping spinal cord and brain doses at safe levels. In a small group of patients irradiated at our facility, tumor control to date has been excellent with a low incidence of normal tissue damage (See Table 2).

Table 1. Heavy particle clinical trial patients, July 1975 to September 1982.

Anatomic region	Helium	Heavy-particle
Head/neck	16	21
Intracranial	31	29
Ocular	84	—
Thoracic	43	17
Abdomen	134	42
Retroperitoneal	13	3
Pelvis	19	2
Skin and subcutaneous	2	5
Totals	342	119
Low LET photon control patients (randomized pancreas trial)	30	
Total patients in trial	491	

Table 2. Dose localization with helium ions for juxtaspinal or base of skull tumors.

Site	Status		Tumor dose	Mean survival
	Number of Patients	No Evidence of Disease	(GyE)	(months)
Sacral Chordoma	4	3	36	25
Clival Chordoma	6	5	75	
Base of Skull Meningioma	2	1	70	7
Juxtaspinal Tumors	6	6	65	23
Totals	18	15 (83%)		

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†Energy and Technical Services Division (Mechanical Technology Group), LBL.

OCULAR MELANOMA

As of March 1, 1982 we had completed treatment in 62 patients with ocular melanomata, with followup to 49 months (Table 3). Twenty patients received 70 GyE in five fractions, with failure to control the tumor in one patient due to presumed resistant tumor and in two patients from marginal misses in which a portion of the tumor was incompletely irradiated. One additional patient in this dose group had a multifocal ciliary body tumor with disease recurring outside of the irradiated volume. The average survival at this dose level is 25 months with 11 of 20 patients retaining useful vision.

Forty-two patients received 80 GyE in five fractions with failure to control the tumor in one patient. A second patient required enucleation because of glaucoma following irradiation of a very large lesion. Although there was shrinkage of the tumor, it is unclear whether control would have been achieved. The average survival in this group of patients is only 10 months with useful vision preserved in 29 of 42 patients.

The results in irradiation of ocular melanomata indicate the potential of significantly increasing the tumor dose relative to the dose to normal tissues. Although a longer followup is needed before drawing firm conclusions in this study of a slowly evolving tumor, a tumor control rate of better than 90% with preservation of useful vision in most patients is quite promising.

CARCINOMA OF THE PANCREAS

We have now completed a pilot study and a randomized trial of helium-ion therapy in over 100 patients with carcinoma of the pancreas. There is approximately a 15% incidence of control within the irradiated area using these techniques, but only a very small level of long term remission (about 3-5%). The randomized prospective study (LBL-NCOG 3P81/RTOG 79-10) did not show a significant advantage for helium-ion therapy over standard low LET irradiation. Therefore we have started a Phase I-II trial incorporating heavy-particle irradiation together with multidrug chemotherapy in hopes of improving overall results in this disease.

CARCINOMA OF THE ESOPHAGUS

Twenty-two evaluable patients were accrued in a Phase II nonrandomized prospective study for helium-ion irradiation of localized carcinoma of the esophagus (NCOG protocol 3E81/RTOG 79-09). Only 18% of these patients have had local control of their tumors, with a median survival of 9 months. This is not an improvement over historial results with standard irradiation techniques. We are now continuing this trial using heavy-particle irradiation so as to study an additional 25 patients in the next two to three years. If some evidence of improved results is seen a prosepctive Phase III trial will be planned.

Table 3. Ocular melanomata treated with helium ion radiotherapy.

Dose Level (GyE)	Number of patients treated	Failure of radiation	Useful vision	Mean survival (months)
70	20	4	11/20	25
80	42	2	29/42	10
Totals	62	6 (9.7%)	40/62	17

HEAVY PARTICLE PHASE I-II STUDIES

During the next two years we will concentrate on Phase I-II heavy particle studies of cancer of the head and neck area, esophagus, stomach, pancreas, and malignant glioma of the brain. In these studies we will be preparing for Phase III prospective trials by evaluation of acute and subacute response of normal tissues and tumors, development of effective treatment techniques, and clinical evaluation of the physical and biological dose distributions possible with heavy particles.

We plan to complete these Phase I-II studies with heavy particles by late 1983 or early 1984 so that prospective Phase III trials can begin. This will coincide with the upgrading of the local particle injector so as to facilitate the clinical trial by freeing it from reliance on the SuperHILAC.

Current patient accrual through the NCOG, RTOG and Bay Area Heavy Ion Association is running at about 110 patients per year with plans to increase this to about 150 per year if possible. Continued support for this project has been made possible by the NCI and DOE.

RADIOTHERAPY PHYSICS

George T. Y. Chen, J. Michael Collier, Samuel Pitluck,* and Todd Richards

The Radiotherapy Physics Group is involved in clinical physics in support of the heavy ion radiotherapy program. Activities include research and development in the technical aspects of optimal heavy charged particle therapy, and clinical physics service for patients under treatment. Highlights of these activities during the past year are described here.

Interactive CT Displays. Axial computerized tomography (CT) slices provide anatomical and quantitative data required for treatment planning. It is often useful to view these data from other perspectives (e.g., saggital, coronal, or oblique). The capability of interactively selecting arbitrary views derived from transverse scans has recently been developed. A sample image is shown in Fig. 1. An axial slice is initially chosen and a cursor is then positioned at the point where coronal or saggital images are desired. This point is then entered, and the corresponding multiplanar views are generated. Using the virtual memory capabilities of the VAX 11/780, up to 32 slices of CT data, each 320 × 320 in dimension, may be loaded and stored for interactive manipulation. Approximately 10 seconds are required for the coronal image; the saggital image requires up to 32 seconds. Target contours defined on axial slices may also be overlaid on these multiplanar reconstructions. These views show the geometric position of the radiation field relative to critical structures and bony landmarks without the image degradation due to overlying tissues usually found in conventional radiographs. These generated images are an important aid in portal alignment and beam delivery.

Interactive Dose Computations. Over the past year, a new version of the dose computation program has been developed, with the capability of calculating and displaying dose distributions interactively. Input parameters

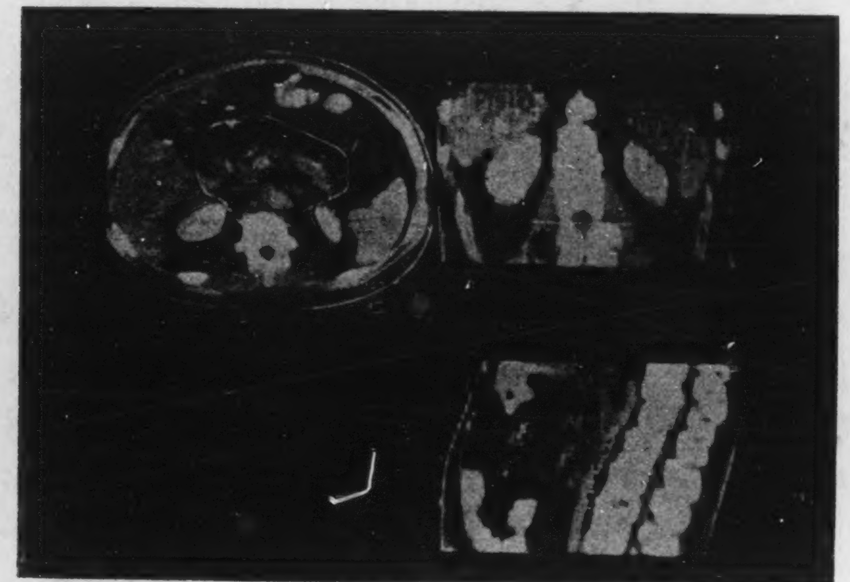

Fig. 1. (a) Transverse, (b) coronal, and (c) sagittal images generated from sequential axial scans. Target volume projections are shown on the coronal and sagittal views. *(XBB 820-10441)*

for each beam include ion type, field weight, angle, size and position, block compensators, target contours, etc. A subset of these parameters may be automatically extracted from target contour information (e.g., beam width, spread Bragg peak and field location). Calculation times are approximately 10 seconds per beam. The plan output is displayed via colored isodose lines overlaid on the CT image, as shown in Fig. 2. Point dose readouts may be obtained interactively through use of the cursor. Single field dose distributions are easily obtained to examine each field's contribution to the composite treatment plan.

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Dose Volume Histograms. Isodose distributions on single or selected CT levels yield partial information on dose to structures. Frequently, dose gradients exist across a specific organ of interest. For example, as shown in Fig. 2, the dose to the left kidney ranges from 100% to 0%, depending on sampling location. Furthermore, dose distributions at one level give no information on the irradiated kidney volume at other levels. We have been investigating the use of dose volume histograms to evaluate the radiation burden to critical structures and uniformity of dose to the target. A differential dose volume histogram is generated by tabulating the dose in all volume elements of a three dimensional structure. The differential dose volume histogram for the left kidney is shown in Figure 3a. The ordinate plots the percentage of organ volume, while the abscissa delineates the dose normalized to target dose. This histogram points out that a substantial fraction of the left kidney is irradiated to approximately 50% of the tumor dose. An integral form of the dose volume histogram is shown in Fig. 3b. The ordinate plots that fraction of the organ that receives at least the dose found on the abscissa as defined by the curve. In this example, over 75% of the left kidney is irradiated to 25% of the tumor dose, and about 20% of the left kidney volume is irradiated to a dose greater than 50% of the tumor dose. However, summing both right and left kidney dose volume histograms, it is clear that kidney function is not at risk. Figure 3c shows the differential dose volume histogram for the target volume. The target is virtually entirely irradiated to the desired 100% level over its three dimensional volume.

Dosimetry. Research and development efforts are underway to improve clinical dosimetry capabilities. Beam

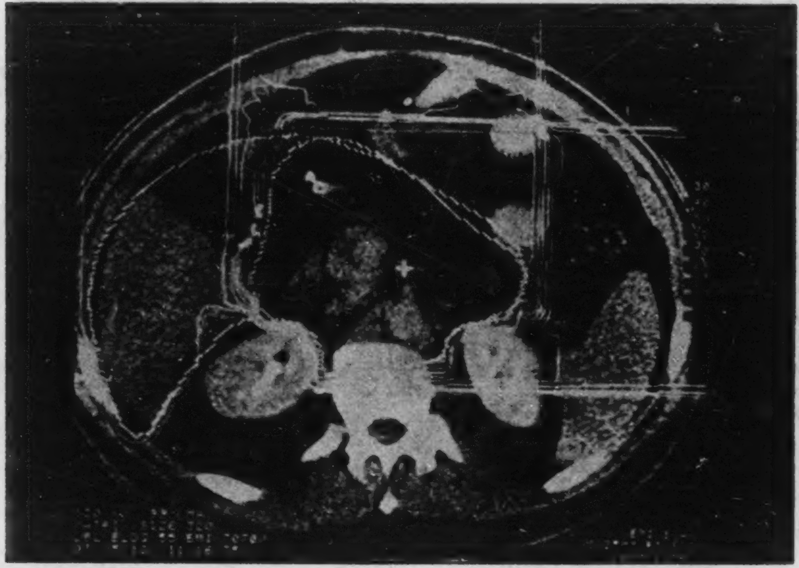

Fig. 2. Composite treatment plan for a pancreatic tumor (small contour). Part of the treatment also included the liver (large contour). The cone-down volume was treated with compensated anterior and lateral fields. The liver and target field was irradiated with a compensated anterior field.
(XBB 820-10443)

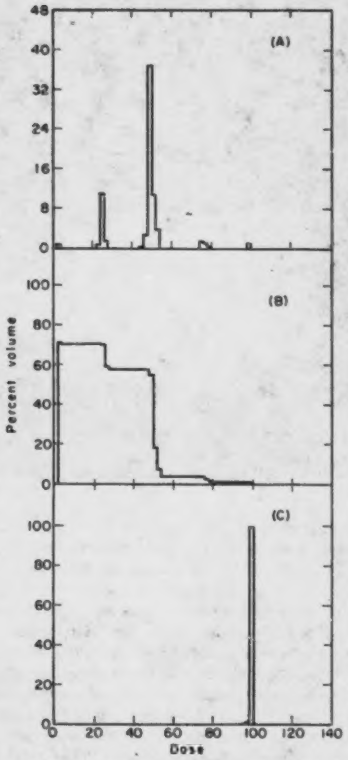

Fig. 3. (a) Differential dose volume histogram of the left kidney. (b) Integral dose volume histogram of the left kidney. A given point on the curve indicates the fractional volume of left kidney receiving more than the corresponding fraction of target dose. (c) Differential dose volume histogram of target, indicating uniformity of dose received by the target volume in three dimensions. (XBL 8211-4265)

characteristics at the 184-Inch Cyclotron make three-dimensional ion chamber measurements feasible and practical, and efforts are underway to computerize this task. We believe that nuclear track detectors at the Bevalac, as developed by Dr. Eugene Benton of University of San Francisco, are an elegant technique for clinical dosimetry that yields both dose and radiation quality data. Collaborative efforts to develop these detectors are underway. In the interim, film dosimetry studies have been conducted to establish the precision with which charged-particle beams may be shaped under clinical conditions. Figure 4 is a photograph of a phantom used in preliminary dosimetry studies. The phantom is constructed of Rando type material, and includes a curved entrance surface, air, compact bone and muscle inserts. The objective of this study is to determine with what accuracy a charged

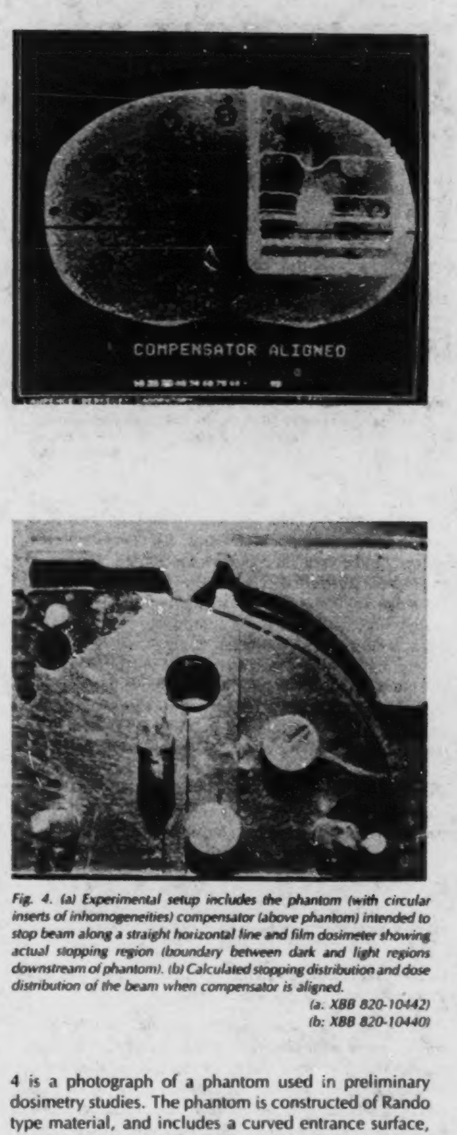

Fig. 4. (a) Experimental setup includes the phantom (with circular inserts of inhomogeneities) compensator (above phantom) intended to stop beam along a straight horizontal line and film dosimeter showing actual stopping region (boundary between dark and light regions downstream of phantom). (b) Calculated stopping distribution and dose distribution of the beam when compensator is aligned.

(a: XBB 820-10442)
(b: XBB 820-10440)

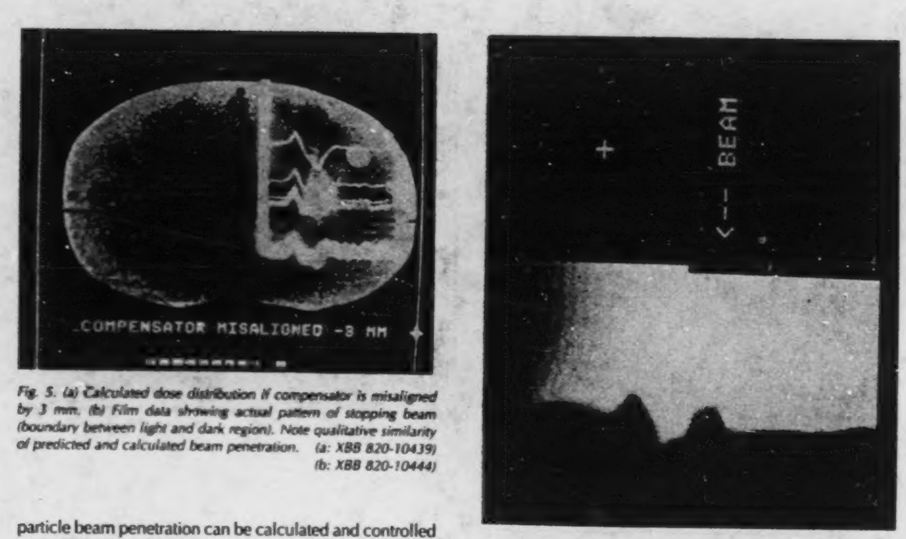

Fig. 5. (a) Calculated dose distribution if compensator is misaligned by 3 mm. (b) Film data showing actual pattern of stopping beam (boundary between light and dark region). Note qualitative similarity of predicted and calculated beam penetration. *(a: XBB 820-10439)* *(b: XBB 820-10444)*

particle beam penetration can be calculated and controlled in the presence of inhomogeneities. A rectangular target volume has been defined as shown in Fig. 4b. The beam enters from above the phantom in Fig. 4a. Ideally, for this target volume, the beam should be stopped along a straight horizontal line if the appropriate compensating bolus is constructed and aligned. Fig. 4a also shows a photographic film exposed on edge behind the phantom. The boundary between the darkened film and the lighter area defines the stopping region of the beam. These data show that the beam does not stop along a straight horizontal line. Variations of approximately 4 mm are seen in the region of the air/bone shadow. These variations are an approximate measure of the accuracy with which compensation can be used to control penetration. This particular experimental setup is one of the more stringent situations encountered clinically. The partial alignment of an air cavity and dense bone of 2.5 cm thickness is infrequent. Thus this test is of a rather extreme case. Figure 5a shows the corresponding calculated dose distribution if a 3-mm compensator misregistration is intentionally entered. Figure 5b shows the experimentally measured stopping region under these circumstances. Agreement between calculation and experiment are within 2 mm. Film, although fast and having high spatial resolution, is sensitive to LET variations of the beam and to particle tunnelling, and is a measure of the stopping distribution of charged particle beams rather than a measure of dose. Other measurements in the abdomen suggest that charged particle beams may be stopped with confidence to within 2-3 mm of the desired point.

HEAVY-ION RADIOGRAPHY

Jacob I. Fabrikant, Cornelius A. Tobias, William R. Holley, Eugene V. Benton, Kay H. Woodruff, and Eric W. MacFarland

High energy, heavy-ion beams offer superior discrimination of tissue electron densities at very low radiation doses. This characteristic has potential for diagnostic medical imaging of neoplasms arising in the soft tissues and organs because it can detect smaller inhomogeneities than x rays. Heavy-ion imaging may also increase the accuracy of cancer radiotherapy planning involving use of accelerated charged particles. In the current physics research program of passive heavy-ion imaging, critical modulation transfer function tests are being carried out in heavy-ion projection radiography and heavy-ion computerized tomography. The research goal is to improve the heavy-ion imaging method until it reaches the limits of its theoretical resolution defined by range straggling, multiple scattering, and other factors involved in the beam quality characteristics. Clinical uses of the imaging method include the application of heavy-ion computerized tomography to heavy-ion radiotherapy planning, to the study of brain tumors and other structures of the head, and to low-dose heavy-ion projection mammography, particularly for women with dense breasts where other methods of diagnosis fail. The ions used are primarily 300 to 570 MeV/amu carbon and neon ions accelerated at the Lawrence Berkeley Laboratory Bevalac.

PASSIVE HEAVY-ION RADIOGRAPHY

The geometry used for heavy-ion radiography is shown in Fig. 1. The external beam channel is long; the beam is brought to a focus near the entrance of the room and allowed to expand until it is about 40 cm wide. If it is assumed that scattering is negligible, then the extent of deviation at the detector is smaller than 0.2 mm for any location in the patient's tissues. If the beam is moderated by an interposed absorber in order to put the stopping points of the particles to a desired depth in the detector, then this value is increased due to multiple elastic scattering. The best position of the attenuator is at the focal spot (beam focus), and the optics of the beam remain essentially unchanged if a relatively thin absorber is inserted there. We have designed a binary filter for range adjustments in radiography that is placed adjacent to the focal spot. A special device, the particle fluence propeller, is also placed into the beam; it makes the particle fluence uniform in the cross section of the beam. At the expense of beam intensity, it is possible to reduce the focal spot size further by an interposed aperture.

These principles are being applied for better diagnosis of soft tissue tumors. In heavy-ion mammography, for example, the mean electron density of normal breast tissue is about 0.98 of that of water, adipose tissue has an electron density of 0.91 to 0.96, and tumor densities range from 1.02 to about 1.06. Heavy-ions demonstrate these densities with ample contrast; however, often a dense region for heavy-ions is undetectable with x rays at diagnostic dose levels. Both heavy ions and x rays have characteristic blind regions in which water and tissues of varying composition cannot be readily distinguished on the image. Unfortunately, these regions often conceal tumors from diagnosis. Figure 2 illustrates the additivity of electron densities and of attenuation coefficients for different components of tissue. It is assumed that tissue consists of three components: water (w, I = 33%), adipose components (1, II = 33%), and supporting connective and parenchymal tissues (s, III = 33%) containing denser protein and structural components. Generally, the heavy-ion number (τ) and the Hounsfield number (H) are different from each other and approach equality only if very high energy x rays are compared to heavy ions. Figure 2 (upper panels) illustrates the relationship of the contribution of components of electronic stopping power to total stopping for heavy ions and the contribution of partial attenuation to total attenuation for x rays. The middle panels illustrate the blind spot for x

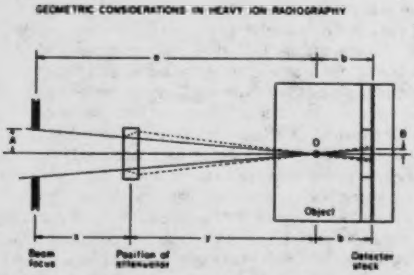

Fig. 1. Geometry of the heavy particle beams for diagnostic imaging. The beam is brought to a focus of less than 1 cm at A. The object-focus distance, a, is about 15 m. The detector stack is in immediate contact with the object, or with a water bath surrounding it, so that the object detector distance is 0 to 40 cm. A stack of attenuators that control the range are placed at distance X. *(XBL 829-4067).*

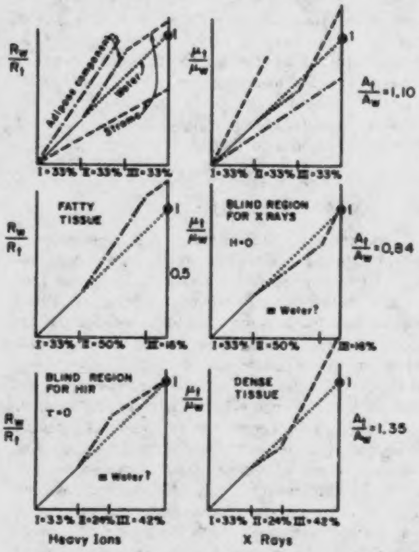

Fig. 2. Illustration of the existence of blind regions for x rays and for heavy ions at certain critical tissue compositions (see text for details).

rays that occurs at a particular ratio of the three components of tissue. However, at the x-ray blind spot, the heavy ions detect a difference from water. Finally, the lower panels indicate the location of the blind spot for heavy-ions; however, the x-ray attenuation per electron is different from that of water. We believe that combined use of x rays and of heavy ions might be quite important for the early detection of cancer.

The graphs (Fig. 2) illustrate the existence of blind regions for x rays and for heavy ions at certain critical tissue compositions. It is assumed that tissue is made up of three components: water (I), adipose components (II) and protein structural components (III). *Upper panels:* It is assumed that the arbitrary tissue composition I = II = III = 33%. In the left panel, the rate of energy loss is different in each component, so that the range ratio $R_w/R_t < 1$, where R is the residual range of heavy ions in water (w) and tissue (t). In the right panel, for the same composition, the attenuation ratio $A_t/A_w > 1$, where A is the x-ray attenuation coefficient per electron in tissue (t) and water (w), and μ is the x-ray absorption coefficient in tissue (t) and water (w). *Middle Panels:* It is assumed that here the arbitrary composition of tissue components is I = 33%; II = 50%; III = 16%. In the left panel $R_w/R_t = 1$, so that heavy ions detect a difference. In the right panel, the attenuation in tissue is the same as in water $A_t/A_w = 1$ so this is a blind region for x rays. *Lower Panels:* Here, I = 33%; II = 24%; III = 42%. In the left panel, $R_w/R_t = 1$, the range of a heavy particle is the same in tissue as in water, so this is a blind region for heavy particles. In the right panel, $A_t/A_w = 1$, so x rays can detect a difference. In actual tissues, the concentration of water is much higher and the observed ratios are nearer to unity than shown here.

HEAVY-ION MAMMOGRAPHY

Soon after the initial techniques of examination of the female breast by x-ray mammography had been developed, it became apparent that normal individuals presented with differing parenchymal patterns. By 1967, attention was drawn to the association between the parenchymal pattern of the breast on x-ray mammography and the presence of carcinoma of the breast. Subsequently, the incidence of the development of carcinoma in the breast with various parenchymal patterns was studied. Specification of the parenchymal pattern has potential use in limited situations to identify the risk category of well women with respect to the future development of carcinoma. Until recently, only little attention has been paid to the differing parenchymal patterns demonstrated by x-ray mammography, and the limitations of conventional x-ray mammography in the assessment of differing patterns in association with early neoplastic change.

Since 1976, all heavy-ion mammograms carried out at the Lawrence Berkeley Laboratory have been classified using a system similar to that used for conventional x-ray mammography. Various associations between the parenchymal patterns and other factors are being identified. The value of the identification of the parenchymal pattern in the mammogram interpretation are being examined, and the variations in heavy-ion density distributions are being quantified. The use of carbon and neon ions for heavy-ion mammography has now been evaluated in 39 patients. In three of these patients, heavy-ions detected dense tissue regions not seen by x-ray mammography that were later proven to be cancer.

The heavy-ion technique appears to be particularly of value in patients with dense breasts; 20 millirad of carbon particles are sufficient to produce high contrast images of diagnostic quality of the human breast. It is important, however, to use optimal image reconstruction and display techniques. In addition to displaying isodensity contours, it is useful to display density gradient images and to prepare density distribution spectra. As these analyses and display techniques improve, heavy-ion mammography will be performed on patients with dense breasts where other diagnostic methods have failed to give an unambiguous diagnosis. Quantitative electron density comparisons are made between left and right breasts.

Stopping Power Density Distribution Histogram Analyses

The stopping power density distributions determined as a consequence of range distributions are used in heavy-ion mammography in a visual display so that diagnostic information can be derived from them. However, it is possible to carry out statistical analyses of the density distribution patterns for mathematical analysis of the internal topography of breast tissues. The distribution of normal density patterns between left and right breasts of the same individual exhibit a degree of symmetry, while these patterns are markedly different from one individual to the next. For example, abnormal densities due to cysts often appear most clearly when deviations between density patterns of the abnormal and the normal breast are studied.

The quantitative nature of heavy-ion range data provides opportunities for further image processing. In each heavy-ion mammographic examination, a gray scale image, electron isodensity contour map, and electron density gradient map heavy-ion number frequency distribution histogram of each breast is created. Each of these data formats provides a different representation of the electron density data for quantitative analyses. The gray scale mammographic image (Fig. 3a, upper left) is produced by assigning decreasing tones of gray to increasing electron density. The average electron density at each pixel is displayed as its corresponding gray tone. In this image,

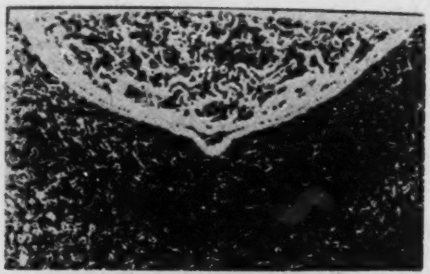

Fig. 3a. Computer-synthesized carbon-ion (250 MeV/amu) mammogram of left breast of patient with breast cancer; this is the gray-scale representation of electron density changes. A small region of increased density in breast parenchyma was detected on the x ray mammogram, but the nature of the density could not be determined. The areas of suspected pathological tissue are readily identified on the carbon-ion mammogram. (XBB 8111-10208).

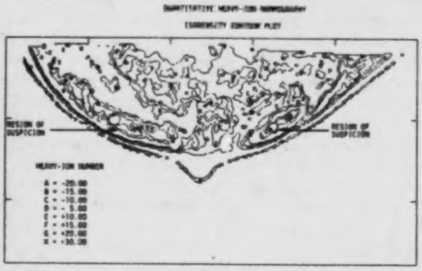

Fig. 3b. Isodensity contour map of the gray-scale carbon-ion mammogram. Isodense regions are outlined and the residual range of the charged particles, after passing through the breast, is identified by letters near each contour. A low residual range value indicates a region of high tissue electron density. The areas of suspicious pathological breast tissue are noted. (XBL 828-10927).

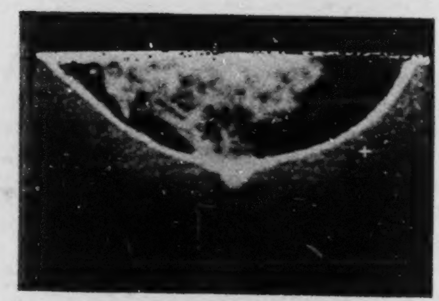

Fig. 3c. Computer-produced electron density gradient map derived from stopping-power values in the carbon-ion mammogram. This is a gray-scale image representation that enhances contour borders and quantifies electron density distribution of normal and abnormal regions. (XBB 826-5179).

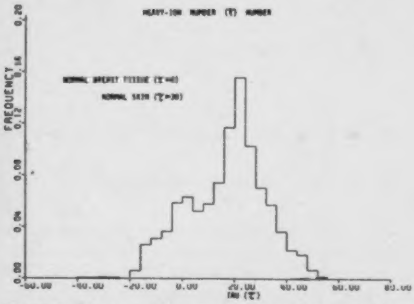

Fig. 3d. Stopping-power frequency-distribution histogram of heavy-ion (τ) numbers derived from the computer-synthesized carbon ion mammogram. Normal and abnormal breast tissues appear as separate peaks with different ranges of heavy-ion (τ) numbers. (XBL 8111-4335)

electron-dense tissue near the center of the breast is abnormal and is the site of suspected pathological (e.g., cancerous) breast tissue; it appears light relative to the surrounding normal tissue. On the other hand, normal breast tissue, due to its lipid content and structure, has an electron density and heavy-ion number (τ) lower than water. The gray scale image is displayed on a television monitor where the contrast level and window may be altered for diagnostic interpretation (assessment of characteristic parenchymal patterns of normal and pathological breast tissues).

Figure 3b, (upper right) is the electron isodensity contour map of outlining regions of constant average electron density. In patients where the contrast of the gray scale image does not reliably delineate detailed structure, e.g., small tumors hidden in dense tissue, this quantitative representation can be of value. This representation provides characteristic radiological patterns and quantitative information for the density values along each contour. The isodensity contour map can be compared with the gray scale image confirming borders and quantifying the electron density of abnormal regions. Values of normal and abnormal electron density can be obtained from measured stopping power values. The stopping power values of normal and neoplastic tissues derived from digitized heavy-ion radiographs of pathologic specimens demonstrate the potential for diagnosis of benign and malignant neoplasms of the breast by diagnostic imaging and accurate quantitative densitometry of the stopping power distribution in the breast tissue. From studies on formalin-fixed mastectomy specimens using heavy-ion radiography, the calculated stopping power values relative to water were: normal breast tissue, 0.957 ± 0.004; mammary dysplasia, 1.016 ± 0.011; and infiltrating ductal carcinoma, 1.064 ± 0.003. The large difference in stopping power between mammary dysplasia and carcinoma may lead to a quantitative method for differentiating between benign disease and breast cancer using heavy-ion radiography. Furthermore, improved depth resolution may be specific-tissue heavy-ion dependent and may prove to be more accurate with heavier ions, e.g., neon and argon, that have improved resolution characteristics.

As a further aid in delineating the boundaries of tissue structures, an electron density gradient map is produced (Fig. 3c, lower left). Here, the absolute value of the first derivative of the electron density with respect to position is plotted. Rapid changes in electron density values at boundaries are readily displayed and identified.

The frequency of occurrence of specific heavy-ion numbers (τ) may be recorded on a distribution histogram (Fig. 3d, lower right). Because living tissue is heterogenous, precise electron density values have limited meaning. Statistical analysis of the distribution of average density values is presently under investigation; thus far, 28 heavy-ion mammogram breast patient studies have been plotted. The presence of relatively large portions of dense (high τ values) tissue compared to the known normal distribution may lead to the identification of areas of pathologic breast tissue. The density values read from the plot can be used for assigning contour values in the isodensity contour map to help identify the tissue regions responsible for the peaks. The low density portions are predominantly due to adipose tissue. High density peaks (τ greater than normal) result from high density regions seen in the gray-scale image and in the isodensity contour map. Tissue studies have shown the τ values of normal breast tissue to be in the range of $\tau = -10.00$ to more than 0.00 and, for carcinomas, in a much higher range of τ. In this study, the pathological breast tissue had a heavy-ion number distribution that peaked in the range of about $\tau = 25.00$ and, for normal skin, τ was greater than 30.00.

DIAGNOSTIC STUDIES WITH HIGH ENERGY RADIOACTIVE BEAMS

Aloke Chatterjee, William M. Saunders, Janis S. Scherer, Edward L. Alpen, Jorge Llacer,* and George T. Y. Chen

Cancer patients are now being routinely treated with energetic heavy charged particles. If the energy of the particles is properly determined during treatment planning, it is possible to deliver a maximal dose to the treatment volume while sparing the adjacent normal cells or vital organs. At present, treatment planning is accomplished by using a CAT scanner. In this technique there can be an error of 2 to 5 mm in localizing the Bragg peak, depending upon certain therapeutic situations. The objective of the present research is to obtain a better accuracy than provided by the CAT scanning method. Such an accuracy can be attained by using high energy beams of radioactive nuclei that decay by positron emission at the stopping point of the beam. Hence by detecting the positron-annihilated γ-rays in coincidence mode (using a suitable positron camera), the range-energy relationship in a heterogeneous object, such as in a patient, can be determined with 1-mm accuracy. The purpose of the proposed work is to develop this idea in a practical way and demonstrate its usefulness in the treatment of cancer patients.

High energy radioactive beams are obtained from the Bevalac as secondary particles. Nuclei of stable isotopes are accelerated in the synchrotron and made to undergo nuclear fragmentation through a beryllium block placed inside the accelerator ring. There are many components in the fragmented beam but only one is the desired radioactive beam. This beam can be magnetically filtered, and through proper beam optics it is brought to a focal point in the therapy cave. Through this procedure, we have been able to obtain beams of ^{11}C (half-life: 20 min) and ^{19}Ne (half-life: 17 sec) in sufficient flux to proceed with the studies for diagnostic applications.

Several studies involving the physical characteristics of radioactive beam particles have to be completed before the beams can be used in clinical trials. Some of these studies and related measurements are described below.

PHYSICAL MEASUREMENTS

Water-equivalent thickness of a silicon diode. The purpose of this measurement was to estimate the water-equivalent thickness of a silicon diode. Data were taken with both a ^{20}Ne primary beam and a ^{19}Ne secondary beam. From the stopping power theory it is well known that the water-equivalent thickness should be independent of the particle charge, mass, or energy.

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* Instrument Science Section, Engineering & Tech. Services Division

There are two main reasons for making these measurements. First, the ^{19}Ne beam is produced from the peripheral nuclear fragmentation collision between the parent beam of ^{20}Ne and a 1-in. thick beryllium target. Thus, ^{19}Ne can be produced at any depth in the beryllium target. Also, the secondary fragment ^{19}Ne can have any velocity according to the Gaussian distribution with the most probable value being the velocity of the parent particles. Hence, the ^{19}Ne beam has more energy spread than the parent ^{20}Ne beam. For the parent beam the energy spread is only 0.1%. The question we wished to answer was, will this spread in energy have any influence on the determination of water-equivalent thickness?

Secondly, silicon diodes will be used routinely in the development stage of the radioactive beam diagnostic technique. They will be used, through ionization measurements, to confirm the Bragg peak localization estimates using PEBA. For ionization measurement with diodes, one has to make a correction to estimate the actual depth of beam stopping by taking into consideration the water-equivalent thickness of a silicon diode. These detectors have the advantage of cheapness, responsiveness, and adaptability for implantation in animal tissues.

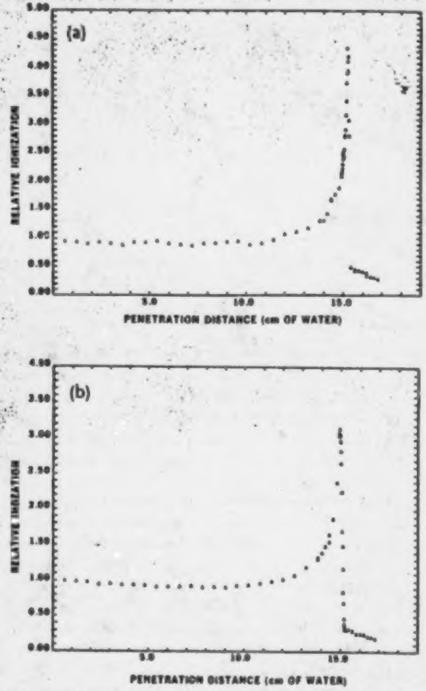

Fig. 1. The Bragg ionization curve for neon-20: (a) as estimated with ion chambers; (b) as estimated with a silicon diode. (XBL 819-7003; XBL 819-7004)

In order to determine water-equivalent thickness of the silicon diode, depth vs. dose ionization curves were measured using gas-filled ion-chambers and a variable water absorber. Measurements were then made substituting the diode detector for the ion chamber. The difference in depth at which the Bragg peak occurs in the two cases yields the water-equivalent thickness of the solid state detector.

Various Bragg ionization curves were obtained using both ^{20}Ne and collimated ^{19}Ne beam. Measurements were made by using ion chambers as well as silicon diodes. The Bragg ionization curve for ^{20}Ne at 383 MeV/amu, as estimated with ion chambers, is seen in Fig. 1a. The Bragg peak occurs at 15.2 cm. For the same beam, when a silicon diode is used, the peak in ionization occurs at 14.94 cm as seen from Fig. 1b. The Bragg ionization curve for the ^{20}Ne beam is quite sharp, indicating a very small spread in energy for the primary ^{20}Ne beam. The difference between 15.2 cm and 14.94 cm is 0.26 cm, which is the water-equivalent thickness of the silicon diode as measured with ^{20}Ne.

Similar Bragg curves were obtained with the secondary ^{19}Ne beam and the results are shown in Figs. 2a and b. When only ion chambers are used, the Bragg peak appears at 10.23 cm in contrast with the silicon diode measurement, for which the peak was at 9.90 cm. The difference between these two readings is 0.33 cm, the water-equivalent thickness of the silicon diode as measured with the ^{19}Ne beam. Thus, we find that there is a difference of 0.07 cm between the measurements made with primary ^{20}Ne and the secondary ^{19}Ne beam. It is well known that the water-equivalent thickness should be independent of the particle charge or energy. We attribute this difference to a rather large spread in beam energy of the ^{19}Ne ions compared to the Bevalac primary particles, such as in the ^{20}Ne beam.

Although there is a difference, the usefulness of the high energy radioactive beam will in no way diminish because the accuracy desired in most therapeutic situations is of the order of 0.1 cm.

A comparison of water equivalent thickness measurements. Silicon diodes were implanted in the brain, neck, thorax, and lower and upper abdomen of a frozen dog. In each of the regions, water-equivalent thicknesses were measured by a computerized axial tomography method. With various heavy particle beams ($^{4}_{2}$He, $^{12}_{6}$C,

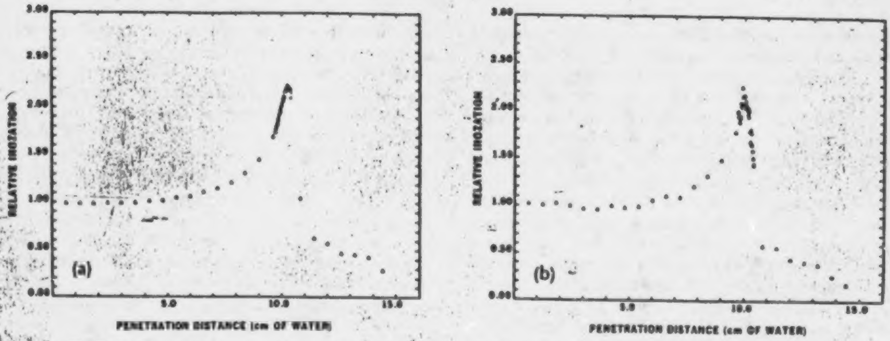

Fig. 2. The Bragg ionization curve for neon-19: (a) as estimated with ion chambers; (b) as estimated with a silicon diode.
(XBL 819-7005;
XBL 819-7006)

$^{11}_{6}$C, $^{20}_{10}$Ne and $^{19}_{10}$Ne), a variable water column was so adjusted that maximum ionization was registered by the diode of the region under consideration. Hence a comparison between the beam technique and the CAT scanning technique could be made on the various values of the water-equivalent thickness. In the areas of the abdomen and neck, the respective values agreed very well. But in the rest of the locations there were differences of the order of 4 to 5 mm. When a comparison was made between the various beams, the agreement was within ± 1 mm in each of the locations.

Magnetic Field Studies

BIOLOGICAL EFFECTS OF MAGNETIC FIELDS

Tom S. Tenforde, Cornelius T. Gaffey, Michael S. Raybourn, and Lynette Levy

Numerous research, industrial and medical technologies involve human exposure to intense magnetic fields. Several newly developing energy technologies, including fusion reactors, magnetohydrodynamic systems, superconducting magnet energy storage rings, superconducting ac generators, and superconducting transmission lines, utilize intense fields produced by superconducting magnets. High magnetic field levels are also associated with several types of research and industrial operations, including bubble chambers, accelerators, superconducting spectrometers, isotope separation units (Calutrons), aluminum production (pre-bake anode cells and Soderberg cells), and the induction heating processes used for plastic sealing, welding, and steel production. A potential future mode of public transportation that will utilize high fields is the magnetically-levitated vehicle, which is currently in the prototype development stage. In medicine, proton magnetic resonance provides a powerful new tool for imaging lipid-rich structures such as the myelinated nerves of the brain and spinal cord. Pilot studies at several institutions have demonstrated that NMR imaging gives detailed information on the demyelination defects that occur in certain pathological disorders such as multiple sclerosis. Phosphorus-31 NMR is also being used for quantitative measurements of the levels of ATP, phosphocreatine, phosphorylated sugars and inorganic phosphates in living tissues, thereby providing metabolic information by a noninvasive technique.

The increasing number of applications of high magnetic fields has created a need to determine the level of exposure of humans in the various technologies, and to evaluate the potential health effects of such exposures. In one of the three ongoing DOE-supported programs at the Lawrence Berkeley Laboratory, a portable magnetic field dosimeter has been developed that continously records the magnetic field level and its time rate of change

4.2 88-Inch Cyclotron

i. What new science is being explored by this facility? What scientific opportunities are being exploited?

Answer: The wide variety of beams and energies available from the 88-Inch Cyclotron supports diverse research programs at the forefronts of several scientific fields.

A. Nuclear Reactions Induced by Heavy Ions:

The phenomena observed from the collision of heavy ions with target nuclei change drastically over the energy range of the cyclotron's beams. A new detector system detects all the charged fragments that are emitted, thus separating the different types of reactions that can occur. The objective is to obtain a unified picture of the reaction mechanisms from the lowest to the highest bombarding energies.

B. Studies of Exotic Nuclei:

Nuclei with unusually high ratios of protons to neutrons are produced by the bombardment of targets with intense beams of such light ions as ^{3}He. The decay properties of these "exotic" nuclei can then be studied. Current work concentrates on the study of nuclei that decay by the delayed emission of two protons, a new type of radioactivity that was discovered at the 88-Inch Cyclotron. An outside user group uses the cyclotron to produce nuclei of elements beyond element 100 for studies of their chemical and nuclear decay properties.

C. Nuclei with Very Rapid Rotation:

Heavy ion beams are used to produce nuclei in a state of very rapid rotation. The numbers and energies of the gamma rays emitted by these nuclei are measured and the results are used to infer the way in which the shapes of nuclei are altered by the fast rotation. The two principal investigators were awarded the American Physical Society's Bonner Prize for this work.

D. Experiments Using Beams of Polarized Protons and Deuterons:

Beams of spin-polarized protons and deuterons are used to study the spin-dependence of the forces between the neutrons and protons inside nuclei as well as the basic symmetries of nuclear interactions in charge, space, and time.

E. Applied Research:

(1) The 88-Inch Cyclotron provides the radioisotopes that are used by the LBL Biomedical Division. The short-lived isotopes ^{11}C and ^{15}O are used with Positron Emission Tomography for studies of blood flow and of metabolism. Compounds made with ^{11}C are used to investigate the brain chemistry in schizophrenia and Alzheimer's (old age) disease as well as in studies of recovery following heart attacks.

(2) The integrated circuits used in space flights must be resistant to cosmic rays. Krypton ions from the 88-Inch Cyclotron are used to test virtually all the types of integrated circuit chips that are used in NASA missions.

(3) Thin films adhere much better to surfaces after exposure to beams of heavy ions. A California Institute of Technology group uses the 88-Inch Cyclotron beams to investigate this technique which may have important commercial applications.

(4) Studies are being made of spin polarization effects in the d + t and d + 3He fusion reactions. Enhanced fusion reactivity can be obtained by the use of polarized particles.

2. **How does this facility's accelerator (or accelerators) performance compare with any other in the world that are operating, under construction, or planned?**

Answer: The LBL 88-inch Cyclotron accelerates both light and heavy ions; the proton and deuteron beams can be spin-polarized. Most accelerators worldwide specialize in one or the other of these capabilities. The great diversity of this cyclotron's capabilities makes it a particularly valuable machine in a multidisciplinary laboratory/university environment such as at Lawrence Berkeley Laboratory and University of California at Berkeley.

The LBL 88-Inch Cyclotron rates very high in the comparison of light and polarized ion capabilities and ahead of the large majority of United States accelerators in heavy ion energy. Worldwide, only the Texas A&M, Grenoble, and Osaka machines have comparable light ion, heavy ion, and polarized beam capability.

3. **What types of research instrumentation/experimental devices are available at this facility, and what are their capabilities?**

Answer: The research equipment at the 88-Inch Cyclotron can be classified into two groups: (1) general purpose equipment that supports a variety of experiments and is often used by several groups and (2) special purpose equipment that may be used by just one group or even for a single (but major) experiment.

A. General Purpose Equipment:

(1) High resolution magnetic analysis system: two 110 degree magnets with maximum resolution of 1.5 x 10-4

(2) Magnetic spectrometer: Quadrupole-sextupole-dipole system, with resolution of 3 x 10-4, solid angle of 2 msr.

(3) Time-of-flight system: 2 meter flight path, time resolution of 400 ps, solid angle of 0.3 msr.

(4) Scattering chambers: 60" diameter, 36" diameter (2), 24" diameter.

(5) Computers: Two ModComp "classic" main frames with modest peripheral devices.

B. Special Purpose Equipment:

(1) Recoil Atom Mass Analyzer (RAMA): He-jet fed, on-line isotope separator (unique).

(2) Polarized ion source: 10 microamperes of polarized protons for injection into the cyclotron.

(3) Sum crystal spectrometer and multiplicity filter for gamma rays.

(4) Eight Ge detectors with BGO Compton suppression (unique).

(5) The plastic-box--a 4-pi detector for charged particles: 12 scintillators, each 20 cm x 20 cm x 0.2 cm (unique).

(6) Spinning Wheel Analyzer for Millisecond Isotopes (SWAMI): Rotating target system (5000 rpm) and solid state fission detectors (unique).

(7) High-pressure hydrogen target for (p,p) scattering. Tests parity conservation.

(8) High-level Cave: Heavily shielded cave and remote target handling facility for production of medical isotopes.

4. **What have been the facility's research highlights for the period FY 1981 - present, and what are anticipated for the remainder of FY 1984 and FY 1985?**

Answer: The research highlights can be summarized under the categories used in responding to Question 1.

A. Nuclear Reactions Induced by Heavy Ions

The existence of the transition region--the range of bombarding energies from 10 - 100 MeV/nucleon where the characteristics of low energy reactions change rapidly and merge with high energy phenomena--was discovered in the late 1970's by physicists at the 88-Inch Cyclotron. Since then, this area, still largely unexplored, has received worldwide attention.

Recent highlights at the 88-Inch Cyclotron have been:

(1) The development of a small streamer chamber to separate the competing reaction mechanisms, transfer and sequential breakup, by visual techniques (FY 1981).

(2) The development of the plastic box--a novel 4-pi charged particle detector that is orders of magnitude more efficient (FY 1982).

(3) The demonstration that transfer reactions occur with significant probability for high energies and large mass transfer (FY 1981-1983).

(4) The development of the overlap model--a nuclear reaction model that explains many features found with the plastic box and unifies reactions at low and high energies (FY 1984).

(5) The demonstration, through systematic measurements of linear momentum transfer from projectile to target, that the significant parameter governing the "missing momentum" is the relative velocity at contact (FY 1983-1984).

(6) The first demonstration of prompt fragmentation of a heavy-ion projectile, ^{7}Li, through angular correlation measurements.

B. Exotic Nuclei

A new form of radioactive decay--delayed two proton emission--was discovered in FY 1983. The proton rich nucleus ^{22}Al, which has a half life of only 70 milliseconds, exhibits this very rare decay mode. One other case, ^{26}P, has been found since then.

A number of proton rich nuclei in this mass region, among them ^{20}Mg, ^{22}Al, ^{24}Si, ^{26}P, and ^{36}Ca have been discovered here in the last five years. Measurements of their masses have demonstrated that the isobaric multiplet mass relation holds with remarkable precision.

In the medium mass range (A of about 120), it has been demonstrated (FY 1983) that equilibrated compound nuclei can decay by the emission of unexpectedly heavy fragments (such as oxygen or fluorine).

In the transfermium region (Z of about 100), an abrupt change in the fission characteristics of these very heavy nuclei has been discovered by a group from Lawrence Livermore National Laboratory. Although there is no theoretical rationale for this at the moment, it is thought to be associated with the changing importance of shell effects.

In the last five years, a number of spontaneous fission isomers have been discovered at the 88-Inch Cyclotron. In the near future, their masses will be determined. At the moment, there is evidence for the discovery of a new isotope of element 104, ^{260}104.

C. High Spin Nuclei:

The interplay between single-particle and collective motion, and how this is changed by rapid rotation, is central to this nuclear structure research.

Recent highlights are:

(1) The discovery of the giant dipole resonance, built on the deformed, rotating states and the development of the special experimental techniques needed to study their properties.

(2) The discovery of major shell effects at very high angular momentum from properties of continuum gamma-ray spectra.

(3) The discovery of higher "backbends" (the second and third) in the rotational sequences of nuclei.

D. Spin-polarization Studies:

Fundamental aspects of the nuclear force are revealed through measurements of spin-observables. These are difficult experiments requiring high precision. In FY 1981-1984, the parity nonconserving part of the nucleon-nucleon interaction was demonstrated through measurement of a nonzero asymmetry in the scattering of longitudinally polarized protons by a hydrogen target.

E. Applied Research:

Use of ^{18}F and ^{11}C labelled compounds and the PET scanner have led to the discovery that Alzheimer's disease is correlated with reduced metabolism of sugar in certain parts of the brain. This can be used to diagnose the disease and to further the understanding of the biochemical changes associated with it.

The flexible scheduling procedure at the 88-Inch Cyclotron is a crucial advantage for the testing of integrated circuits for single-event upset susceptibility. When it was learned shortly before the scheduled launch of a satellite in October, FY 1983 that certain chip types on board had not been tested, it was possible to perform the tests on short notice--three days before the (ultimately successful) launch.

5. **What facility changes and additions have occurred or are anticipated for the period FY 1981 - FY 1985?**

Answer: There has been a continuing program of accelerator improvements and upgrades since the commissioning of the 88-Inch Cyclotron. Two of the most recent major projects--the construction of an Electron Cyclotron Resonance (ECR) ion source (in progress) and installation of a new ionizer for the polarized ion source in FY 1981 are discussed in more detail below. Other improvements to the Cyclotron in the years from FY 1981 through FY 1984 include the development of an improved internal heavy ion Penning Ion Gauge (PIG) source, additional cryopumping in the Cyclotron and modification of the rf system to improve its reliability.

The construction of an ECR ion source, which will be the first coupled to an accelerator in the United States, will result in a major improvement in the performance of the 88-Inch Cyclotron. Injection of the high charge state heavy ions from the ECR into the Cyclotron will result in an increase in the maximum energy available from the Cyclotron for ions between oxygen and argon by a factor of 2 to 3, respectively. Also the operational efficiency of the Cyclotron will improve markedly with the addition of the ECR, since down-time for ion source changes will be eliminated. Design, procurement, and fabrication of the beam transport system, which will couple the ECR source to the 88-Inch Cyclotron, are underway with installation scheduled for September 1984.

The addition of a new ionizer and improvements to the axial injection system in FY 1981 increased the intensity of the polarized proton and deuteron beams from 100 nA current available out of the Cyclotron to 700 nA. A project to design and demonstrate the feasibility of producing narrow phase width beam pulses (about 1 ns) from the Cyclotron began in FY 1984. The long term goal will be to use the short burst beam pulses for neutron time-of-flight measurements. During FY 1985, it is anticipated that the dee voltage regulation system will be replaced by a feedback network using an amplifier with a large gain-bandwidth product which will reduce the dee voltage fluctuation. This improved regulation is necessary to attain the narrow phase width beam. It will also improve the extraction efficiency of the cyclotron for light ion and heavy ion beams.

6. **For the period FY 1981 - FY 1985, please provide actual and estimated budget profiles for operations, in-house research, out-ofhouse research, other operating expenses, Capital Equipment, General Plant Projects, In-House Energy Management, and any other specific construction projects attributable to the facility. Please indicate the source of these funds (i.e., Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).**

Answer:

88-Inch Cyclotron
(B/A in thousands of dollars)

Source of Funding	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Accelerator Operations					
Heavy Ion NP	$ 1,180	$ 1,261	$ 1,260	$ 1,435	$ 1,495
Low Energy NP	572	575	528	541	565
TOTAL	$ 1,752	$ 1,836	$ 1,788	$ 1,976	$ 2,060
In-house Research					
Heavy Ion NP	$ 1,851	$ 2,002	$ 1,027	$ 1,496	$ 1,555
Low Energy NP	541	461	1,155	957	997
TOTAL	$ 2,392	$ 2,463	$ 2,182	$ 2,453	$ 2,552
Out-of-house Research					
Heavy Ion NP	$ 0	$ 55	$ 45	$ 50	$ 50
Low Energy NP	0	10	10	10	10
TOTAL	$ 0	$ 65	$ 55	$ 60	$ 60
Equipment/Operations					
Nuclear Physics	$ 27	$ 19	$ 20	$ 20	$ 40
Nuclear Physics*	0	0	650	950	0
TOTAL	$ 27	$ 19	$ 670	$ 970	$ 40
Equipment/Research					
Nuclear Physics	$ 217	$ 416	$ 413	$ 225	$ 319
Accelerator Improvement					
Nuclear Physics	$ 75	$ 53	$ 0	$ 0	$ 0
General Plant Projects					
Nuclear Physics	$ 0	$ 0	$ 0	$ 55	$ 0

* ECR Source

7. How much funding for FY 1981 - FY 1985 has been or is expected to be provided by other federal agencies such as the National Science Foundation or by State agencies?

Answer: None.

8. For the period FY 1981 - FY 1985, please provide actual and estimated staffing levels.

Answer:

Staffing Associated with 88-Inch Cyclotron

Fiscal Year	Man Years
1981	22
1982	22
1983	22
1984	22
1985	22

The cyclotron operations staff includes accelerator physicists, mechanical and electrical engineers, cyclotron operators, mechanical technicians, and other support personnel.

9. What is the actual and estimated facility utilization for the period FY 1981 - FY 1985? What would be defined as "full" utilization of the facility?

Answer: For the period FY 1981 - FY 1985, actual and estimated utilization of the 88-Inch Cyclotron is given in the following table.

88-INCH CYCLOTRON UTILIZATION

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985
Beam Hours for Research	4164	3609	3445	3500	3500

For the 88-Inch Cyclotron, we estimate full utilization to be 6000 beam hours for research per year.

10. For the period FY 1981 - FY 1985, how many experiments will have been started, continued, and completed?

Answer: For the five year period FY 1981 - FY 1985, approximately 375 experiments will have been started, 350 experiments will have been completed, 25 experiments will be continuing. Records for FY 1981-1983 show that an average of 75 experiments are accomplished per year. An experiment may be completed in one or two cyclotron runs or may be part of a larger program extending over several or more runs. Most experiments are completed within a few months, although an on-going program may extend over a year or more.

11. What is this facility's user policy?

Answer: As a national facility, the 88-Inch Cyclotron is open to all qualified users from institutions both within and outside the United States. Proposals for nuclear science research are evaluated by a program advisory committee (C. K. Gelbke, Michigan State University (chairman); C. D. Goodman, Indiana University Cyclotron Facility; J. Randrup, Lawrence Berkeley Laboratory).

A users executive committee (K. Van Bibber, Stanford University (chairman); F. S. Dietrich, Lawrence Livermore Laboratory; M. A. Stephens, Lawrence Berkeley Laboratory) represents the interests of all users. It advises laboratory management on any matters affecting users. The executive committee maintains the users organization membership list (104 individuals) and distributes a newsletter at regular intervals to a mailing list of 225 people. The fraction of beam time going to outside users has remained fairly constant over the past five years and has varied between 25% and 30%. This fraction is not set by policy and reflects the demand by outside users.

12. **For the period FY 1981 - FY 1985, how much reimbursable research has taken place or is estimated to take place? What revenues have been involved?**

Answer: None.

13. **What is the mechanism by which specific research proposals for experiments at the facility are considered?**

Answer: Proposals for individual experiments or for continuing research programs in nuclear science may be submitted at any time to the Scientific Director and are transmitted immediately to the Program Advisory Committee (PAC). The PAC functions by mail and by telephone. No presentations to the Committee are required. Scientific merit and the appropriateness of the proposed research for the cyclotron are the main factors considered in the review process. Proposals from outside users and from LBL users are considered on the same basis. Recommendations from the PAC are usually available within two weeks of the receipt of the proposal. Approved experiments are then scheduled on a weekly basis. Outside users who must make travel arrangements are accommodated with advance scheduling. Very short experiments that are done infrequently (e.g., tests of detectors, short irradiations, etc.) are scheduled at the discretion of the scientific director.

14. **How many research proposals have been submitted over the past five years, and how many of these have been approved?**

Answer: The present proposal review mechanism was instituted in June 1983 after the 88-Inch Cyclotron was designated a national facility. Research proposals were not made before that date. Since then (i.e., in the past 9 months), 13 proposals for research have been received. Of these, 11 have been approved, 1 has been rejected, and 1 is under consideration. About half of these proposals were for continuing research programs and these will be resubmitted annually. The remainder were for individual experiments. Occasionally, outside users will do experiments in close collaboration with in-house groups. In some of these cases, the experiment may be approved within the framework of the in-house group.s annual proposal. Very short experiments that are done infrequently (e.g., tests of detectors, short irradiations) are scheduled at the Scientific Director's discretion.

15. How many university personnel (i.e., faculty and students) have utilized the facility over the past five years?

Answer: An average of 37 university personnel utilized the 88-inch Cyclotron each year during the past 5 years. Approximately one half of these people are regular users of the 88-inch Cyclotron. They have appointments at University of California at Berkeley or other nearby universities and often are concurrently on the staff of LBL. University of California graduate students may also hold Graduate Student Research Assistant positions at LBL. The remaining researchers are visiting faculty members and their students from other universities who come for one or more runs. In some cases, faculty members are on leave from their home university and are spending their sabbaticals at the 88-inch Cyclotron. Some of the visiting faculty and students are from foreign institutions.

16. How many industrial researchers have utilized the facility over the past five years?

Answer: An average of 33 industrial researchers utilized the 88-inch Cyclotron each year during the past 5 years.

17. How many researchers from foreign institutions have utilized the facility over the past five years?

Answer: An average of 23 researchers from foreign institutions and supported by foreign funds utilized the 88-inch Cyclotron each year during the past 5 years. These people include faculty and students from foreign universities who have visited for short periods (one or two runs), faculty and students who have stayed for longer periods, exchange program personnel, and researchers paid by grants or fellowships from their governments while on leave from their home institutions.

18. How many researchers from other agencies have utilized the facility over the past five years?

Answer: Four scientists from the Veterans Hospital, San Fernando, California used the facility from FY 1981-1983.

19. What are the future development possibilities for this facility (including research instrumentation/experimental devices), what plans are being made to exploit these possibilities, and what are the budgetary implications?

Answer: There are many potential future development possibilities for this accelerator facility, but there are currently no approved plans to undertake any of them beyond the activities identified in the FY 1985 budget request. New research instruments and experimental devices will be developed as the physics research program progresses. We intend to give high priority to the exploitation of the facility.s unique capabilities.

20. Please provide a copy of the facility's latest annual report.

Answer: Information on all aspects of 88-inch Cyclotron operations and research is contained in the attached annual report of the Nuclear Science Division. The latest report was dated June 1983 and became available in December 1983. It covers the period 1981-1982. **(Note: Excerpts from this report follow.)**

LBL-15207

Nuclear Science Division

Annual Report for the Period July 1, 1981 – September 30, 1982

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88-Inch Cyclotron Operations and Research

Operations

D.J. Clark, D. Elo, L. Glasgow, R. Lam, C.M. Lyneis, R.G. Stokstad

The 88-Inch Cyclotron, operated by the Nuclear Science Division, provides a large fraction of the beam time that is used by Division scientists. Variable energy high resolution beams from hydrogen through argon are produced and used for studies of nuclear structure and nuclear reaction mechanisms. The cyclotron is also the Laboratory's major source of medical isotopes and its only source of polarized proton and deuteron beams.

The cyclotron is now operating at an increased value of the energy constant, K, of 160 for ions heavier than $A = 4$. Ions as heavy as ^{40}Ar can be accelerated to the Coulomb barrier of 5 MeV/u, while lighter heavy ions can reach 20–30 MeV/u. The cyclotron thus operates in the important transition region between low and high energies: 10–30 MeV/u.

As a national accelerator laboratory the 88-Inch Cyclotron is used extensively by outside groups from many institutions in the U.S. and abroad. Table I shows the number of users from LBL and elsewhere. Scheduling of experiments for the cyclotron is done in an open meeting on a weekly basis with a lead time of only eight days. Outside users who must make travel arrangements in advance are accommodated with advance scheduling. A users' organization has been formed and a program advisory committee instituted. The members of the users' executive committee are Karl Van Bibber (Stanford University), Chairman; Frank S. Dietrich (Lawrence Livermore National Laboratory); and Marie-Agnes Deleplanque (LBL). C. Konrad Gelbke of Michigan State University serves as Chairman of the Program Advisory Committee. Charles Goodman (Indiana University) and Jørgen Randrup (LBL) are the other two members.

The 88-Inch Cyclotron plays a significant educational role. At present 13 graduate students from the University of California at Berkeley are employing this facility in their research toward the Ph.D. degree. Three students received their doctorates from UCB in 1982 for research done at the cyclotron. Four graduate students from other universities are also involved in research at the cyclotron.

Table I. Number of users of the Cyclotron during the past year, FY82.

LBL Staff, University of California, Berkeley Campus			17
Graduate Students			
	U.C. Berkeley	14	
	Other Universities	5	
			19
Post-doctoral scientists			
	LBL	5	
	Other laboratories	3	
			8
Outside users and visitors			
	Industry	30	
	Universities, National Labs.	52	
			82
	TOTAL		126

The cyclotron now operates 14 1/2 eight hour shifts per week with one shift for maintanence at the beginning of the week and one half shift for shutdown on the weekend. It was operated for 20 shifts per week until October 1981 when increased power rates and budget limitations made the reduction in running time necessary. The distribution of cyclotron time is shown in Table II. The list of beams available is given in Table III. The particle distribution of light and heavy ion beams during the past 14 years is shown in Fig. 1.

Table II. Cyclotron operating and maintenance time distribution for the 15 month period 7/1/81 to 9/30/82 covered by this Annual Report

		Hours	%
Operating Time			
	Beam Development	435	5.7
	Tuning	656	8.6
	Optics	356	4.7
	On target	3942	51.6
	Waiting for experimenter	338	4.4
	Subtotal	5727	75.0
Maintenance Time			
	Weekly maintenance	390	5.1
	Shutdown maintenance	591	7.7
	Ion source preparation	487	6.4
	Unscheduled maintenance	314	4.1
	Other	126	1.7
	Subtotal	1908	25.0
	Total	7635	100.0
	Shutdown	3045	
	Holiday	288	
	Total Time	10968	

Improvement Programs

The staff is involved in programs to improve the ion sources, the machine, extraction, and beam lines. Improvements to ion sources include a new simpler internal PIG (Penning ion gauge) heavy ion source, an upgrade of the polarized ion source, and a proposal to construct an ECR (electron cyclotron resonance) source. Improvements of the cyclotron itself have centered on upgrading the rf system. Improved extraction efficiency is the goal of the magnetic channel project. The installation of a fast slammer valve in beam line 3 provides better protection of the cyclotron from accidents involving radioactive targets.

A new PIG heavy ion source was designed to increase the source lifetime and to simplify parts and maintenance. Design improvements include simplification of the base insulator and elimination of discharges in the connecting line between cathodes. A prototype was designed and fabricated. It is still being debugged but initial use in experimental runs indicates that it will fulfill its design goals. Modifications are now being made to further improve it and more testing will be done but we expect to build another unit soon so that it can go into steady operation.

A new ionizer was installed in the polarized ion source last year. It was tested and put into service early this year. It has provided approximately a factor of 3 increase in the polarized beams. An additional increase in beam intensity is expected when the pumping speed on the ionizer is improved.

Improvements in the cyclotron rf system include a new crowbar unit for the final amplifier plate supply series regulator. It has 4 additional channels and greater speed and reliability. Under construction is a new regulating system using fibre optic cables for signals between ground and 25 kV points. An rf filter on the final amplifier plate supply is being designed to reduce the number of high voltage capacitors. This will simplify the system and make more spare capacitors available. An all solid-state rf driver amplifier has been installed to replace two tube-type distributed amplifiers. The system will be operational after interlock modifications.

A magnetic channel will replace the third section of the electrostatic deflector. It will provide the stronger deflection strength needed for the higher energy beams made available by the high K operation and by the future ECR source. It consists of a passive iron system about 20 inches long, with no coils. It reduces the magnetic field in the beam region and adds a radially focussing gradient. The channel has been constructed and its field has been measured. The measurements indicate that some modifications are needed to improve the field linearity and to adapt the mechanical support system to the deflector mounting plate.

A fast slammer valve has been installed on the beam line to cave 3 to protect the cyclotron from contamination which could result from a radioactive target accident. The associated electronic controls were also completed.

The ECR Source

The ECR source has been selected as the best type of advanced ion source for the 88-Inch Cyclotron. The choice was made in May 1982 after the two types of advanced ion source, ECR and EBIS (electron beam ion source), were evaluated. The ECR source was chosen because it will provide an energy increase of 2–4 for heavy ion beams up to krypton at adequate intensities for most experiments (10^{10} – 10^{11} particles/second external beam) at 100% duty factor. EBIS, the other source candidate, produces higher charge states, but lower intensity and duty factor. An ECR design workshop was held in August 1982 with participants from Louvain-la-Neuve, Karlsruhe, Oak Ridge and LBL. A proposal to build an ECR source was submitted to the Department of Energy in September 1982. Construction will require about 2 years.

The proposed ECR source is a compact 2-stage system using normal conducting coils, a permanent magnet hexapole, and 8 GHz microwave power. The design includes a number of features that contribute to flexibility and a potential for future development. The second stage coils are subdivided so that the mirror ratio may be varied. The hexapole structure is open and allows radial pumping and access to the plasma for diagnostic elements. Particular attention has been given to the design of the extraction system to improve intensity. The beam transport and improvements in the axial injection system are included in this project.

Table III. 88-Inch Cyclotron Beam List

Ion	Energy[a] (MeV)	Ext. Beam Intensity (eμA[b])
p	0.2 – 55	100 – 20
p (polarized)	6 – 55	1.0
d	0.5 – 65	100 – 20
	65 – 70	~0.5
d (polarized)	10 – 70	1.0
$^{3}\mathrm{He}^{1+}$ [c]	2 – 47	>20
$^{3}\mathrm{He}^{2+}$ [c]	4 – 140	100 – 10
$^{4}\mathrm{He}^{2+}$	3 – 130	100 – 10
	130 – 140~	~0.5
$^{6}\mathrm{Li}^{1+}$ [c]	2 – 23	10
$^{6}\mathrm{Li}^{2+}$ [c]	23 – 93	5
$^{6}\mathrm{Li}^{3+}$ [c]	93 – 195	0.5
$^{7}\mathrm{Li}^{2+}$	20 – 80	5
$^{7}\mathrm{Li}^{3+}$	80 – 180	0.5
$^{9}\mathrm{Be}^{2+}$	15 – 62	5
$^{9}\mathrm{Be}^{3+}$	62 – 140	2
$^{9}\mathrm{Be}^{4+}$	140 – 249	.05
$^{10}\mathrm{B}^{2+}$ [c]	14 – 56	10
$^{10}\mathrm{B}^{3+}$ [c]	56 – 126	50
$^{10}\mathrm{B}^{4+}$ [c]	126 – 224	0.3
$^{10}\mathrm{B}^{5+}$ [c]	224 – 320	0.001
$^{11}\mathrm{B}^{2+}$	12 – 51	10
$^{11}\mathrm{B}^{3+}$	51 – 115	30
$^{11}\mathrm{B}^{4+}$	115 – 204	0.3
$^{12}\mathrm{C}^{2+}$	12 – 47	>20
$^{12}\mathrm{C}^{3+}$	47 – 105	30
$^{12}\mathrm{C}^{4+}$	105 – 212	5 – .5
$^{12}\mathrm{C}^{5+}$	187 – 306	.05 – .001
$^{12}\mathrm{C}^{6+}$	292 – 384	10^{5} p/s
$^{13}\mathrm{C}^{3+}$ [c]	43 – 97	>20
$^{14}\mathrm{N}^{2+}$	10 – 40	20
$^{14}\mathrm{N}^{3+}$	40 – 90	15
$^{14}\mathrm{N}^{4+}$	90 – 160	15
$^{14}\mathrm{N}^{5+}$	160 – 250	2
$^{14}\mathrm{N}^{6+}$	250 – 360	10^{6} p/s
$^{14}\mathrm{N}^{7+}$	360 – 448	100 p/s
$^{15}\mathrm{N}^{4+}$ [c]	84 – 150	15
$^{16}\mathrm{O}^{1+}$	9	1
$^{16}\mathrm{O}^{2+}$	9 – 35	>5
$^{16}\mathrm{O}^{3+}$	35 – 79	20
$^{16}\mathrm{O}^{4+}$	79 – 155	30 – .2
$^{16}\mathrm{O}^{5+}$	140 – 219	5
$^{16}\mathrm{O}^{6+}$	219 – 315	0.3
$^{16}\mathrm{O}^{7+}$	315 – 429	10^{7} p/s
$^{16}\mathrm{O}^{8+}$	429 – 512	0.2 p/s
$^{18}\mathrm{O}^{3+}$ [c]	31 – 70	20
$^{18}\mathrm{O}^{4+}$ [c]	70 – 124	>10
$^{18}\mathrm{O}^{5+}$ [c]	124 – 194	5
$^{19}\mathrm{F}^{3+}$	30 – 66	5
$^{19}\mathrm{F}^{4+}$	66 – 118	10
$^{19}\mathrm{F}^{5+}$	118 – 184	2
$^{20}\mathrm{Ne}^{3+}$	28 – 63	>10
$^{20}\mathrm{Ne}^{4+}$	63 – 112	10
$^{20}\mathrm{Ne}^{5+}$	112 – 175	5
$^{20}\mathrm{Ne}^{6+}$	175 – 252	1
$^{20}\mathrm{Ne}^{7+}$	252 – 343	0.01
$^{20}\mathrm{Ne}^{8+}$	343 – 448	~50 epA
$^{22}\mathrm{Ne}^{5+}$ [c]	102 – 159	~5
$^{22}\mathrm{Ne}^{6+}$ [c]	159 – 229	1
$^{24}\mathrm{Mg}^{4+}$	50 – 93	2
$^{24}\mathrm{Mg}^{5+}$	93 – 146	0.2
$^{25}\mathrm{Mg}^{4+}$ [c]	50 – 90	2
$^{26}\mathrm{Mg}^{4+}$ [c]	48 – 86	2
$^{26}\mathrm{Mg}^{5+}$	86 – 145	.08
$^{28}\mathrm{Si}^{5+}$	80 – 125	1
$^{28}\mathrm{Si}^{6+}$	125 – 180	0.2
$^{28}\mathrm{Si}^{7+}$	180 – 245	0.05
$^{32}\mathrm{S}^{6+}$	100 – 158	2
$^{32}\mathrm{S}^{7+}$	158 – 238	0.2 – .03
$^{35}\mathrm{Cl}^{7+}$	144 – 196	0.5
$^{35}\mathrm{Cl}^{8+}$	196 – 256	0.05
$^{37}\mathrm{Cl}^{6+}$	95 – 136	0.3
$^{37}\mathrm{Cl}^{7+}$	136 – 185	0.08
$^{40}\mathrm{Ar}^{2+}$	3.5- 14	0.4
$^{40}\mathrm{Ar}^{6+}$	87 – 126	4
$^{40}\mathrm{Ar}^{7+}$	126 – 172	2
$^{40}\mathrm{Ar}^{8+}$	172 – 224	0.5
$^{40}\mathrm{Ar}^{9+}$	224 – 280	10^{5} p/s
$^{40}\mathrm{Ar}^{10+}$	280 – 350	10^{3} p/s
$^{40}\mathrm{Ca}^{6+}$	87 – 126	1
$^{40}\mathrm{Ca}^{7+}$	126 – 172	0.2
$^{56}\mathrm{Fe}^{10+}$	180 – 250	1 p/s
$^{63}\mathrm{Cu}^{9+}$	142 – 180	5 enA
$^{63}\mathrm{Cu}^{10+}$	180 – 222	0.1 enA
$^{63}\mathrm{Cu}^{11+}$	222 – 269	5×10^{3} p/s
$^{84}\mathrm{Kr}^{2+}$	1.6- 6.6 [d]	.001
$^{84}\mathrm{Kr}^{8+}$	82 – 107	.250
$^{84}\mathrm{Kr}^{9+}$	107 – 135	.120
$^{84}\mathrm{Kr}^{10+}$	135 – 167	.030
$^{84}\mathrm{Kr}^{11+}$	167 – 202	.003
$^{197}\mathrm{Au}^{13+}$	102 – 120	2 p/s
$^{197}\mathrm{Au}^{14+}$	120 – 140	0.1 p/s

a) Heavy ion range shows nominal maximum energy for a particular charge state down to energy which can be reached by the next lowest charge state. The maximum energy for several heavy-ion beams has been increased to $E = 160\ Q^2/A$ MeV. Beams can also be run at energies below 1 MeV/nucleon.

b) Electrical microamperes except as noted, $\Delta E/E \sim 0.3\%$. Intensity on target will be less, depending on mode of beam transport.

c) Isotopically-enriched source feed.

d) 15th harmonic.

Research

R.G. Stokstad

The research programs at the 88-Inch Cyclotron comprise a broad and diversified enterprise that reflects in part the versatility of the accelerator. Basic research in nuclear physics is done with heavy ion and light ion beams. These probes are used to study nuclear structure and nuclear reaction mechanisms. Interspersed in this effort is a series of application of nuclear techniques to other disciplines The following overview categorizes the research in terms of heavy-ion reaction mechanisms, nuclear structure, exotic nuclei, heavy element research, light ion research and applications.

Heavy Ion Reaction Mechanisms

The study of nuclear reaction mechanisms continues to form one of the main thrusts of the overall research program. Previous developments of beams of beryllium through neon at energies up to ~20 MeV/nucleon have made possible a broad program of investigations into the nature of peripheral reactions, incomplete fusion, fission and evaporation.

The behavior of heavy-ion reactions changes rapidly as the bombarding energy is increased significantly above 8 MeV/n. Between this energy and about 100 MeV/n a transition occurs from the characteristics of low energy phenomena (transfer reactions, complete fusion) to those of relativistic heavy-ion reactons (fragmentation, participant-spectator mechanisms). The mechanisms of heavy-ion reactions in this regime are being studied in order to identify and understand the competing processes and their dependence on the bombarding energy. Two main thrusts of this work are in the areas of transfer and fragmentation reactions and of incomplete fusion. Transfer reactions are being studied by a new device, the "plastic box", a 4π array of scintillators arranged in the form of a cube which provides the means to distinguish between transfer and fragmentation. The plastic box is being used in a number of experiments where the separation of two-body and three-body reactions is crucial. Incomplete fusion is being investigated with the time-of-flight facility. Systematic measurements for a series of targets and ^{16}O energies reveal an onset of incomplete linear momentum transfer at about 5 MeV/n above the Coulomb barrier.

The transition between evaporation and fission is also being explored. As the evaporated particle increases in mass beyond helium, the distinction between the two mechanisms blurs and the question of how to describe the production of complex intermediate-mass fragments arises. This is being approached experimentally by observing the yields of helium through neon produced in the reaction of ^{3}He and Ag and characteristic changes which occur in the shapes of the energy spectra as the mass of the fragment increases (from a Maxwellian shape to a Gaussian shape). These experimental characteristics will be compared with the predictions of theoretical models.

Nuclear Structure

A major effort is directed toward the understanding of the behavior of nuclei at high angular momentum – up to the limit where they fission. For rare earth nuclei in the upper half of this spin region ($30-60\hbar$), the gamma-ray spectrum cannot be resolved and methods have been developed for extracting information from the continuum. In the past few years a new method has been found to measure average effective moments of inertia that include both single-particle and collective contributions. These can be combined with previously measured average "band" moments of inertia (which are mainly collective) in order to separate these two contributions in unresolved spectra for spins in the range of $50-60\hbar$. In some light Er and Yb nuclei at these spins, evidence has been found for a large single-particle contribution due to high-j proton orbitals. These particular orbitals are from the next higher major shell ($N=5$) above the valence shell ($N=4$). In some of the nuclei of this region, the contributions from the two shells are almost completely separated as two broad peaks in the gamma-ray spectrum. Other regions of nuclei are being examined to see if such large shell effects are common.

Exotic Nuclei

Research in the area of exotic nuclei consists primarily of decay studies of light to medium mass very neutron-deficient isotopes. Techniques used for these studies involve charged particle and β-γ spectroscopy of nuclides produced in ^{3}He or heavy-ion bomardments of neutron-deficient targets. These nuclides are transported from the target area via a helium jet system which can be used either to prepare a source directly or to feed the on-line mass separator, RAMA. Recent use of the helium jet system operating alone has permitted discovery of the previously unknown, odd-odd, $T_z = -2$ isotopes, ^{22}Al ($t_{1/2}$ ~70 ms) and ^{26}P ($t_{1/2}$ ~20 ms). Observation of their beta-delayed proton decays has not only provided beta decay and isobaric analog state information but also confirmed a theoretical prediction that both isotopes could decay by a new decay mode, beta-delayed two-proton radioactivity. Subsequent proton-proton coincidence experiments have enabled discovery of this new radioactivity (for both nuclides) and provided initial information on the mechanism of two-proton emission.

Heavy Element Research

Heavy element research is conducted by two NSD groups and a group from Lawrence Livermore National Laboratory. The Long Tape System at the cyclotron was designed to detect a spontaneous fission (SF) activity with $t_{1/2}$ ~0.1 sec against a very high background of longer-lived SF activities. The 0.1-sec activity was never found, down to the sub-nanobarn cross section level, in many experiments utilizing targets of ^{249}Bk and ^{248}Cm with ^{15}N and ^{16}O projectiles. This is in sharp disagreement with claims put forth by Dubna experimenters; however, in these same experiments a 20-ms SF activity with substantial cross sections was detected which has been tentatively assigned to ^{260}Rf. A 100-ms SF activity has been found in bombardments of ^{254}Es with 99-Mev ^{18}O and 73-Mev ^{13}C projectiles. In the first case, the cross secton is very large, about 1 microbarn, and in the second, about 0.2 microbarn. Such large cross sections rule out nuclides with Z equal to 104 or more; the best candidate on the basis of comparative yields is ^{261}Lr, but ^{260,261}Md are also considered possible.

Reaction mechanisms in the heavy element region, where radiochemical techniques provide unique assignments of nuclear mass and charge to the produced radioactive species, has been concentrated in three areas: (a) the production of actinide nuclei by means of a massve transfer of nucleons from the projectile to the target as a potential means of producing new neutron-rich nuclides; (b) determination of the production of nuclei with a greater nuclear charge than the target and the measurement of the charge dispersion of fission-like products from the reaction of 20 MeV/n ^{12}C and ^{16}O beams with targets of gold and rare earths; and (c) measurements of the gamma-ray intensities and population of isomeric states in poorly-known nuclear species produced in heavy-ion reactions. The production and fission of element 104 by the reaction $^{15}\text{N} + {}^{249}\text{Bk} \rightarrow {}^{260}\text{Rf} + 4\text{n}$ is being studied and from about 300 observed events it is seen that element 104 fissions symmetrically. This is in contrast to a preliminary finding based on ~70 events and indicates that shell effects at the second minimum disappear rapidly with excitation energy. The production of actinide nuclei by heavy-ion induced massive transfer reactions has been studied using an ^{254}Es target and beams from both the 88-Inch Cyclotron and the SuperHILAC. Chemical studies of the electrochemical potential for reduction of divalent nobelium have also been carried out.

Light Ion Research

Light-ion research using the polarized proton and deuteron beams is generally concerned with spin-polarization phenomena in nuclear reactions and scattering. A most important feature of polarization effects is that they often display uniquely the operation of, hence the possible violation of, a basic symmetry property of the nuclear interaction. Thus, several fundamental experiments have been designed to make significant tests of parity conservation, charge symmetry, and time-reversal invariance in this interaction.

Spin-polarization measurements also provide information concerning nuclear structure and reaction mechanisms that is not otherwise available. Thus, studies are made of analyzing powers and polarization transfer in inelastic nucleon scattering and nucleon-transfer reactions in order to deduce the specific spin-dependent nature of the nuclear interactions. For example, the inelastic nucleon scattering results provide detailed information about the spin-dependent components of the effective nucleon-nucleon force in nuclei, which is a subject of considerable current interest. Measurements also are made of polarization-transfer in elastic proton-nucleus scattering, since these results will provide a unique means of establishing the existence of a spin-spin component of this nuclear interaction. This research with polarized beams involves collaborations with several groups from different universities and laboratories.

Applications

Grouped as applied research are the activities of (i) the Division of Biology and Medicine, which include radioisotope production and cellular studies of radiobiological effects with low energy heavy ions; (ii) the investigation of cosmic-ray induced errors in digital semiconductor devices; (iii) detector calibration for relativistic heavy-ion physics and space research; and (iv) a new program, the enhanced adhesion of thin films through heavy-ion bombardment.

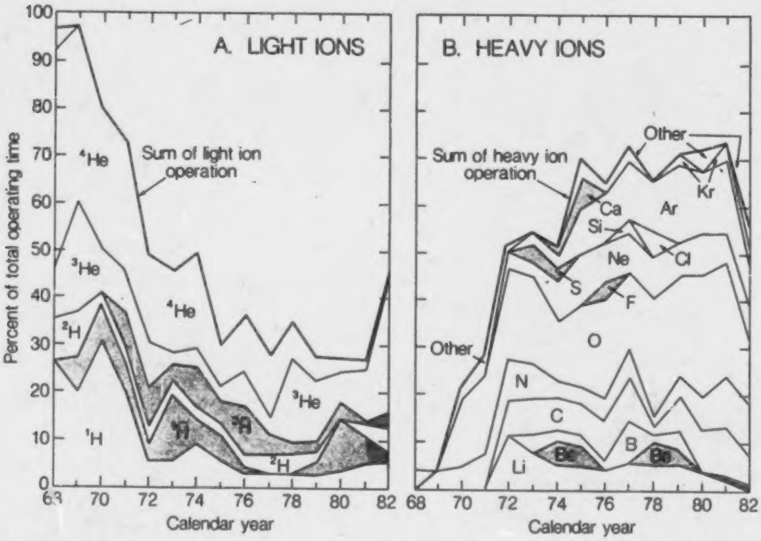

Fig. 1 Distribution of light and heavy ion beams.

XBL 822-1898

PART III: EXPERIMENT

1211

1. Nuclear Structure

General

Decay Properties of Isoscalar Giant Resonances in ^{24}Mg, ^{28}Si, ^{58}Ni, ^{64}Zn, and ^{92}Mo

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and D.H. Youngblood[*]

(α,α',c) coincidence experiments of the charged-particle decay c from the isoscalar giant multipole resonances in ^{24}Mg, ^{28}Si, ^{58}Ni, ^{64}Zn, and ^{92}Mo excited by 128 MeV inelastic α scattering have been performed at the 88-inch cyclotron of the Texas A&M University. The inelastically scattered α particles were detected at 0° in an Enge split-pole spectrograph. This assures axial symmetry of the decay particles c about the beam axis and, in particular, allows the search for the decays of isoscalar (giant) monopole resonances. Analysis of the data has started recently and is in progress.

Footnotes

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Inelastic Scattering of ^{12}C from ^{208}Pb to the Second 0^+ State of ^{12}C*

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A theoretical and experimental investigation of the inelastic scattering of ^{12}C from a ^{208}Pb target exciting the second 0^+ state of ^{12}C has been performed with the 88-Inch Cyclotron at incident energies of 132, 187, and 230 MeV. For those inelastic scattering reactions in which the ^{12}C nucleus is excited to states above 7.37 MeV, but below 15.96 MeV, the only particle emission channel open is $^{12}C^* \rightarrow {}^8Be + \alpha$. These channel fragments are confined to a cone and are detected in coincidence by two $\Delta E \times E$ counter telescopes in close vertical geometry, with one telescope above and one telescope below the reaction plane.

A summed energy spectrum for coincident events in the two telescopes, where at least one telescope records an α-particle, is shown in Fig. 1a[1] for an incident ^{12}C energy of 187 MeV and for the counters placed at 19° to the beam direction. From kinematic arguments the peak at 178 MeV is determined to arise from the quasielastic breakup of ^{12}C into the α and ^{8}Be channel. Most of the yield of this quasielastic peak is due to the breakup from the 0^+, 7.65 MeV state. This may be seen from Fig. 1b[1] which shows the ^{8}Be projected energy spectrum, arising from the quasielastic peak. The different peaks of this spectrum arise from the contribution of different excited states of ^{12}C. Thus, the 0^+, 7.65 MeV state of ^{12}C, which has a c.m. breakup energy of 0.288 MeV, results in a broad peak at 120 MeV, while the 9.64 MeV state results in two narrow peaks.

The angular distributions of the quasielastic peak for the three beam energies are shown in Fig. 2. These have been analyzed in a framework of a microscopic folding model and the DWBA. The real parts of the optical potentials in the initial and final channels as well as the real part of the transition form factor have been calculated by double folding[2] the M3Y effective interaction[3] with the respective densities. The renormalization constants are given in the caption to Fig. 2. It can be seen that a renormalization constant for the final channel other than 0.6 provides bad fits to the experimental data.

These investigations confirm that for loosely bound projectiles the double folding model overestimates the calculated real part of the potential and a renormalization of nearly 50% is necessary to fit the data for inelastic scattering. It is the first time that this effect has been demonstrated by an investigation of inelastic scattering. The M3Y interaction[2,3] with one nucleon exchange taken into account in the zero order appears to provide a good description of the central part of the nucleon-nucleon effective interaction over a range of projectile energies.

Footnotes and References

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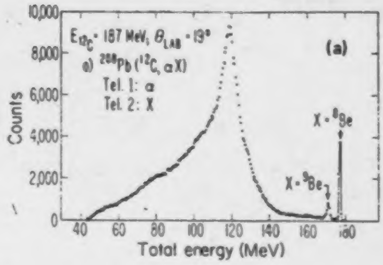

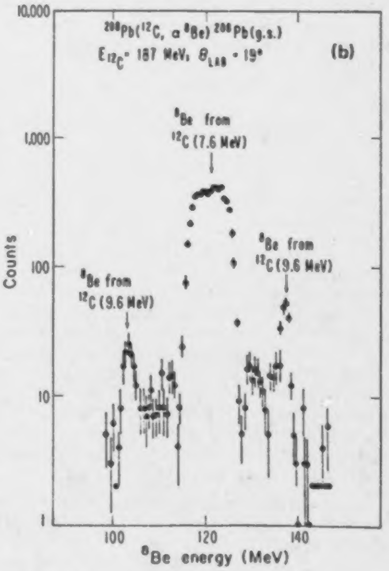

Fig. 1.
(a) The yield of coincident events between the two telescopes. See text.

XBL 807-10713A

(b) The energy of ^{8}Be nuclei in coincidence with an α-particle for the transition ^{208}Pb(^{12}C,α^{8}Be)^{208}Pb(g.s.) at 187 Mev bombarding energy. This projected energy spectrum was taken at Θ_{LAB} = 19° with a detector configuration which has an average vertical angular separation of $\Delta\Phi$ = 5.9°.

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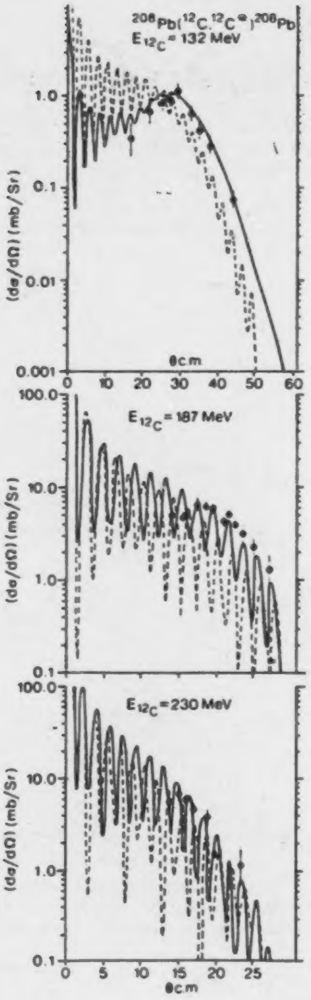

Fig. 2. Inelastic cross section for the excitation of the 0_2^+ state in ^{12}C in ^{12}C + ^{208}Pb collisions. The solid line represents the results of calculations where the renormalization constant of the calculated initial channel real potential was 1.25 and that of the final channel real potential was 0.6. The dashed line represents the results when both the initial and final channel real potentials are renormalized by a factor of 1.25.

XBL 834-9098

Exotic Nuclei

Beta-Delayed Proton Decay of an Odd-Odd $T_z = -2$ Isotope, ^{22}Al[*]

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While the decays of several even-even $T_z = -2$ nuclei have been studied,[1,2] to date no odd-odd $T_z = -2$ nucleus has been characterized. We report the observation of the β^+-delayed proton decay of the first such nucleus, ^{22}Al. The particle stability of ^{22}Al has been a question of interest for many years; most mass models predict ^{22}Al to be at the very limit of particle stability, with some models indicating stability and others not.

^{22}Al was produced via the ^{24}Mg(^{3}He,p4n)^{22}Al reaction by bombarding natural magnesium targets with a 110 MeV ^{3}He beam from the 88-Inch Cyclotron. The recoil atoms were transported with ethylene glycol or NaCl-loaded helium through a 1.1-m long, 1.6-mm diameter capillary onto a catcher foil. β^+-delayed protons were detected by a three-element semiconductor telescope consisting of 110 μm ΔE1, 60 μm ΔE2, and 1000 μm E.

Proton spectra observed at 110 and 60 MeV ^{3}He bombarding energies are shown in Fig. 1. These spectra are dominated by β^+-delayed protons from the decays of ^{25}Si and ^{21}Mg, which are produced at relatively high yield via the (^{3}He,2n) and (^{3}He,α2n) reactions. At 110 MeV, two new proton groups are observed at 7.839 ± 0.15 and 8.149 ± 0.021 MeV, very near the predicted absolute proton energies expected.[3] These groups are not seen in the 60 MeV bombardment, which is below the threshold for producing ^{22}Al. The half-life of these groups was measured to be about 70 ms.

As shown in Fig. 2, these two proton groups were assigned to the isospin forbidden proton decay of the lowest T = 2 state in ^{22}Mg. Using the experimental mass for this state and the calculated[3] Coulomb energy difference between ^{22}Al and ^{22}Mg*, we get a Q_{EC} = 18.493 MeV for ^{22}Al, which indicates that ^{22}Al is bound against direct proton emission by only 102 keV. Comparison of the ^{22}Al yield to that of ^{25}Si and ^{21}Mg indicates an effective cross section for the observed proton groups of about 1.2 nb, which corresponds to a total cross section of 40 nb.

As is also shown in Fig. 2, the beta-delayed two-proton decay of ^{22}Al is energetically possible. A search for the new decay mode is in progress.

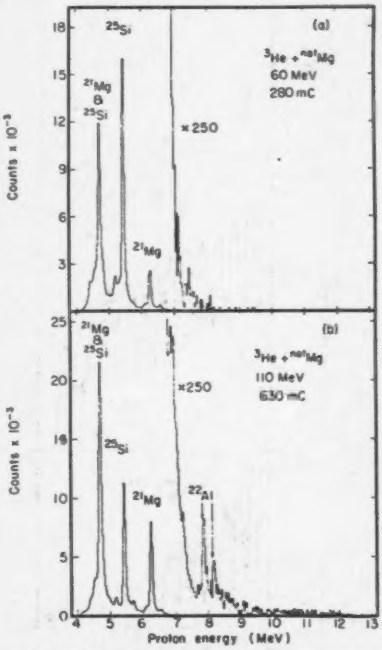

Fig. 1. Beta-delayed proton spectra. The positions of the arrows labeled ^{22}Al are the predicted energies obtained by the method of Hardy, et al. (ref. 3)

XBL 823-3710

Footnotes and References

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[*] Condensed from LBL-14419, Phys. Rev. C26 (1982) 1778, with additions

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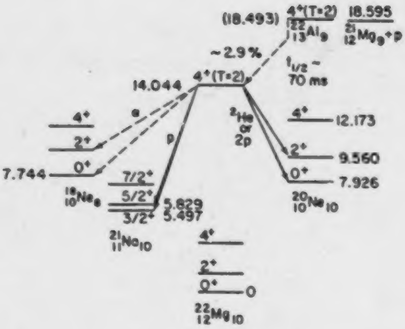

Fig. 2. Partial decay scheme for ^{22}Al.

XBL 829-4626

Beta-delayed Proton Decay of the Odd-Odd T_z = –2 Isotope ^{26}P

M.D. Cable, J. Honkanen, R.F. Parry,*
S.H. Zhou,† Z.Y. Zhou,‡ and Joseph Cerny

Recent observation of the β^+-delayed proton decay of ^{22}Al established the existence of the first known member of the odd-odd A = An + 2, T_z = –2 series.[1] We wish to report the observation of the second such nucleus, ^{26}P. These nuclei are of interest not only for isobaric analog state masses and beta-decay information but are also thought to be at the very limit of particle stability. ^{26}P is actually predicted to be unbound to direct proton emission by most mass formulae.[2] As discussed below, this is quite possibly true and not inconsistent with our observation of this isotope. Also of considerable interest is the energetically possible decay mode of β^+-delayed 2-proton emission for both of these nuclei.

^{26}P was produced via the ^{28}Si(^{3}He,p4n)^{26}P reaction with 110–130 MeV ^{3}He beams from the 88-Inch Cyclotron. The recoils were transported by a helium jet to a counting chamber and collected on a slowly rotating Al wheel. A 3-element semiconductor particle telescope (110 μm ΔE1, 60 μm ΔE2, and 1000 μm E) was used to observe β^+-delayed protons coming from nuclei at the collection site.

Proton spectra observed at 60, 110, and 130 MeV ^{3}He energies are shown in Fig. 1. The spectra are dominated by β^+-delayed protons from the decay of ^{21}Mg, ^{25}Si, and ^{29}S produced in high yield (^{3}He,xα2n) reactions. At 110 MeV and 130 MeV, however, two new groups are observed at 7.269 ± 0.015 MeV and 6.827 ± 0.050 MeV and were observed to decay with a half life of ~20 ms.

As shown in Fig. 2, these two new groups can be assigned to the isospin-forbidden proton decay of the lowest T = 2 state in ^{26}Si. From the known mass of ^{25}Al,[2] the ^{26}Si* mass excess can be calculated to be 5.936 ± 0.015 MeV and a Coulomb displacement estimate of the ^{26}P-^{26}Si* mass difference gives a calculated ^{26}P mass excess of 18.295 MeV. This result indicates that ^{26}P is unbound to direct proton emission by ~34 keV. Since the proton decay half life even for an ℓ = 0 transition is >1 second for a decay energy below ~50 keV (as calculated by the barrier penetrability code,

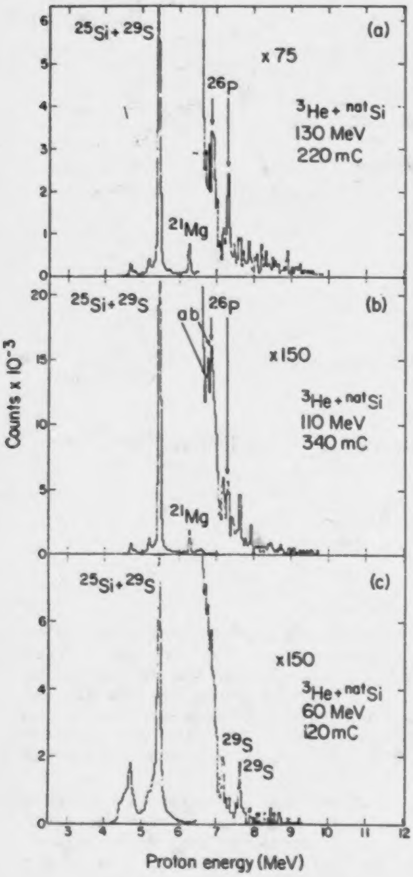

Fig. 1. Beta-delayed proton spectra.

XBL 829-4623

COCAG), beta decay can be the dominant decay mode, in agreement with our data. The observed half life for ^{26}P beta decay gives a superallowed β^+ branch of ~1.9%. As shown in Fig. 2, β^+-delayed 2p emission (an unobserved radioactive decay mode) is energetically possible for this nucleus. Work is progressing to observe this mode of decay.

Footnotes and References

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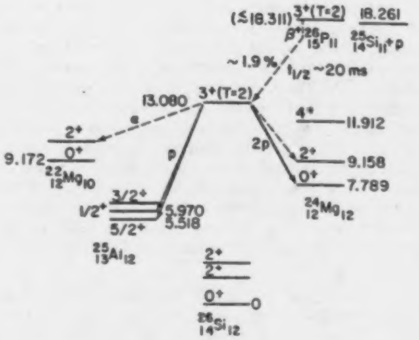
(≤18.311) 3⁺(T=2)
18.261
β^+ $^{26}_{15}$P$_{11}$
$^{25}_{14}$Si$_{11}$+p
~1.9 %
$t_{1/2}$ ~20 ms
13.080
3⁺(T=2)
4⁺
11.912
2⁺
9.158
0⁺
7.789
2p
p
2⁺
9.172
0⁺
$^{22}_{12}$Mg$_{10}$
3/2⁺
1/2⁺
5/2⁺
5.970
5.518
$^{25}_{13}$Al$_{12}$
$^{24}_{12}$Mg$_{12}$
2⁺
2⁺
0⁺
0
$^{26}_{14}$Si$_{12}$

Fig. 2. Partial decay scheme for ^{26}P.

XBL 829-4628

Weak Beta-Delayed Proton Groups in the Decay of ^{21}Mg, ^{25}Si, and ^{29}S

S.H. Zhou, M.D. Cable, J. Honkanen,† R.F. Parry,*
Z.Y. Zhou,‡ and Joseph Cerny

During the study[1,2] of ^{22}Al and ^{26}P, several new low-intensity β^+-delayed proton groups have been observed and assigned to ^{21}Mg, ^{25}Si, or ^{29}S. The results are listed in Table I with intensities given relative to the strongest proton group arising from the decay of each isotope.[3,4] The log*ft* values were calculated assuming that the final states of these β^+-delayed proton decays are only the ground states of the corresponding final nuclides, so that the log*ft* values listed in Table I should be considered as the upper limits. The log*ft* values indicate that all these transitions are allowed. Figure 1 shows the ^{29}S β^+-delayed 7114 ± 15 keV and 7581 ± 15 keV proton peaks and ^{25}Si β^+-delayed 6518 ± 10 keV proton peak. Those proton peaks are firmly assigned and the others in Table I are tentatively assigned.

Table I: Proton Energies, Excitation Energies and log*ft* Values

ISOTOPE	E_{lab} (keV)	$E_{c.m.}$ (keV)	Relative Intensity (%)	E_x (keV)	log*ft*
^{25}Si	6518±10	6792±10	0.5±0.1	9186	4.88±0.01
^{29}Si	7114±15	7370±16	1.3±0.4	10348	5.35±0.07
^{29}S	7581±15	7852±16	0.5±0.1	10830	5.32±0.04
^{21}Mg	6492±20[a)]	6819±21	0.4±0.1	9008	5.02±0.03
^{25}Si	6719±50[a)]	7001±52	0.05±0.02	9395	5.72±0.08
^{25}Si	6808±50[a)]	7094±52	0.3±0.1	9488	5.86±0.04

a) Tentative assignment

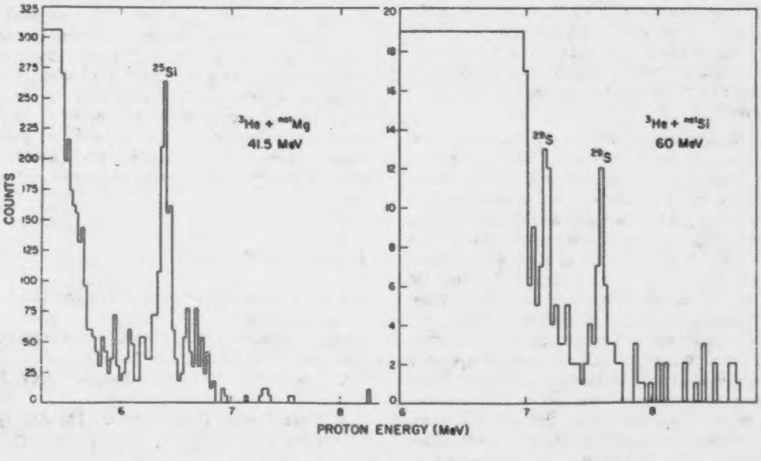

Fig. 1. Proton energy spectra showing β^+-delayed peaks for ^{3}He ions on targets of natural Mg and Si.

XBL 8011-1328

Beta Endpoint Measurements of Neutron-Deficient Cesium Isotopes

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The beta decay energies of neutron-deficient $^{119\text{-}123}$Cs isotopes have been measured. The total decay energies of ^{122m}Cs (Q_{EC} = 6.95 ± 0.23 MeV) and ^{119}Cs (Q_{EC} = 6.26 ± 0.29 MeV) are new measurements based on the 8^- isomeric state in ^{122}Cs decaying to the 2217.3 keV 8^+ level in ^{122}Xe and the $9/2^+$ ground state in ^{119}Cs decaying to the 257.9 keV $9/2^+$ level in ^{119}Xe, respectively. Our measured total decay energies for the cesium isotopes have significantly refined the uncertainty of previous measurements. Comparison of the deduced binding energies of the xenon nuclei from the direct-mass-measured cesium parent isotopes with those of theoretical predictions provides insight into the mass surface in this region of isomer-rich nuclei.

The beta endpoint measurements were accomplished using the 88-Inch Cyclotron on-line mass separator RAMA. Standard beta-gamma coincidence techniques were applied using a ΔE-E beta detector telescope arrangement of NE102 plastic scintillator (15 MeV positron energy range) and a gamma-ray detector (23% coaxial Ge crystal) mounted opposite the plastic telescope. Calibration of the beta detector was accomplished using known beta endpoint energies from the strongest decay branches of ^{124}Cs (4.38 ± 0.14 MeV), ^{66}Ga (4.153 ± 0.004 MeV), and two branches in the decay of ^{64}Ga (6.05 ± 0.03 and 2.79 ± 0.08 MeV). The cesium isotopes were produced via 140 MeV ^{14}N bombardment of ^{nat}CdS and the gallium isotopes by 110 MeV ^{14}N on ^{nat}Ni.

The data were collected using hardwire coincidences between the beta telescope and the gamma detector. Analysis of one component of the beta decay into the daughter xenon nucleus was accomplished by suitable software gating conditions on the desired xenon gamma ray. Endpoint information was established by a "shape fitting" method. Instead of attempting to elucidate a response function correction and using the Fermi-Kurie method, a technique of numerically interpolating between the shapes of calibrated spectra was used, otherwise known as "stretch fitting".[1] A smooth curve is fitted through a standard positron spectrum numerically generating a standard experimental shape. Other intended calibration beta spectra are then normalized in intensity and fit to the standard shape through a nonlinear least squares algorithm, which generates linear stretch factors that are proportional to their endpoint. The result is a linear calibration curve that relates stretch factor to endpoint energy. The unknown nuclei are fit to the standard shape in the same manner. Their stretch factors are then applied to the calibration curve generating endpoint values. This method provides a unique way to avoid both the need for a detector response correction to remove distortion effects and the complicated process of iteration and unfolding common to the Fermi-Kurie technique.

A summary of our measurements, the mass excesses of the xenon nuclei, and comparison with two mass predictions, Liran-Zeldes (L-Z) and Garvey-Kelson (G-K), is presented in Table I.[2-6] The literature values for Q_{EC} of ^{121}Cs and ^{123}Cs have unrealistic uncertainties for the decay measurements involved. Our experimental values of the uncertainties present a more reasonable estimation of the error. It should be noted that the experimental Q_{EC} for ^{122m}Cs implies the isomeric level is quite close to the ground state, which is also noted by Epherre, et al.[7]

An interesting disagreement of about 750 keV between our deduced mass excess of ^{120}Xe and that of the literature values and mass predictions is evident in Table I. There are several possibilities for this discrepancy. The literature mass excess for this nucleus is in error (the value was determined by measuring the ratio of positron emission to electron capture for the decay of ^{120}Xe to ^{120}I); the majority of the beta strength is to a higher-lying 2^+ state in the Xe daughter; or, finally, the mass excess for the parent, ^{120}Cs, has larger uncertainty than reported. The lower-mass cesium isotopes (beginning at ^{120}Cs) denote an interesting region for experimental study because of the onset of observed beta-delayed alpha and proton emission.

Footnotes and References

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Table I: Measured decay energies of the Cs isotopes and deduced mass excesses of the Xe daughters.

Nuclide	Decay Energy, Q_{EC} (MeV)		Xe Mass Excess (MeV)		Δ = ME (this work) − ME (theory[2]) (MeV)	
	This Work	Literature	This Work	Literature	L-Z	G-K
^{123}Cs	4.05±0.18	4.0±0.1[4]	−85.19±0.19	-85.257±0.016	−0.13	−0.08
^{122}Cs	7.05±0.18	7.05±0.40[5]	−85.01±0.20	-85.344±0.414	0.05	0.16
^{122m}Cs	6.95±0.23	–	–	–	–	–
^{121}Cs	5.21±0.22	5.40±0.02[4]	−82.27±0.23	−82.459±0.076	0.08	0.01
^{120}Cs	7.38±0.23	7.3±0.5[6]	−81.19±0.26	−82.028±0.284	0.73	0.86
^{119}Cs	6.26±0.29	–	−78.45±0.32	−78.818±0.156	0.27	0.47

Heavy Actinide Products from Reactions of ^{18}O, ^{22}Ne, and ^{136}Xe with ^{254}Es

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To find the best target-and-projectile combination that gives the highest yield of product for heavy neutron-rich transplutonium isotopes and to gain knowledge about the production mechanism, we carried out a series of bombardments using ^{254}Es as the target nuclide and ^{18}O, ^{22}Ne, and ^{136}Xe as the projectile. In our experiments we used chemical techniques to separate element fractions from a catcher foil after the end of the bombardment, and measured these fractions to obtain α-energy spectra and to count SF events.

Although the data evalution is still in progress, some interesting observations can be made. Cross sections for the Fm and Md isotopes and ^{259}No from the reactions of 121 MeV ^{22}Ne, 125 MeV ^{22}Ne, and 98 MeV ^{18}O with ^{254}Es are shown in Fig. 1. Fermium formation cross sections from 97 MeV ^{18}O + ^{248}Cm were taken from ref. 1 and are shown for comparison.

For the ^{22}Ne + ^{254}Es reaction, we observed only a very slight increase in cross sections as the incident energy increased from 121 MeV to 125 MeV. The shape of the isotopic distributions shown do not shift or change significantly. To determine the most probable mass (Ap), we fitted a Gaussian curve to the data and held σ = 0.977u (FWHM = 2.3) fixed. For the Fm isotopes, we found Ap = 254.5 and Ap(Md) = 256.0.

More neutron-rich products were observed in the ^{18}O + ^{254}Es reaction at 98 MeV incident energy than were found at 121 MeV ^{22}Ne. Ap values of 255.5 for Fm and 257.1 for Md were determined. This makes the ^{18}O the most favorable projectile for the production of neutron-rich heavy actinides when compared to ^{22}Ne.

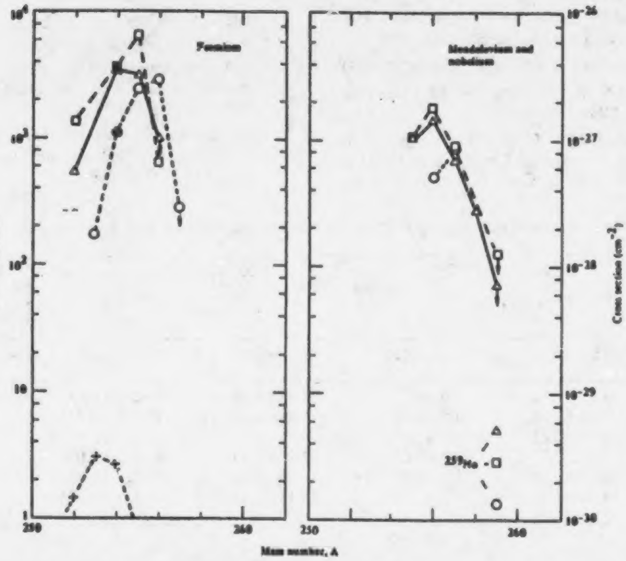

Fig. 1. Cross sections for ^{259}No and Fm and Md isotopes in the reaction 121 MeV ^{22}Ne + ^{254}Es (symbol = Δ), 126 MeV ^{22}Ne + ^{254}Es (symbol = □) and 98 MeV ^{18}O + ^{254}Es (symbol = ○). Cross sections for Fm isotopes in the reaction 97 MeV ^{18}O + ^{248}Cm (symbol = +) from ref. 1 are shown for comparison. Open symbols are independent; full symbols are cumulative yields; arrows indicate that these cross sections are upper limits only. The curves are drawn to connect the data points.

XBL 8210-3289

The Fm cross section is enhanced by a factor of 10^3 and the Md cross section by more than 10^4 when the yields from an ^{254}Es target are compared with a ^{248}Cm target.[1]

Assuming an equal transfer probability for a given number of protons (ΔZ) and neutrons (ΔN) in the reactions with ^{18}O as a projectile on ^{248}Cm and ^{254}Es targets, we were able to extrapolate (^{254}Es,x) cross sections from the cross sections measured with a ^{248}Cm target. This is possible only in these light ion reactions where the excitation energies are less than the neutron separation energies, whereas there are large differences in cross sections for products with the same number of transferred nucleons (ΔZ, ΔN) in reactions with ^{238}U projectiles on ^{238}U and ^{248}Cm targets.[2] This is because of higher excitation energies and differences in Γ_n/Γ_{tot} for the different primary fragments formed. In Fig. 2a, we compare cross sections for a two-proton and x-neutron (ΔN) transfer in the reaction of ^{18}O with ^{248}Cm and ^{254}Es resulting in Cf and Md isotopic distributions, respectively. Positive ΔN values characterize neutron transfer from the projectile to the target, while negative ΔN values refer to transfer in the opposite direction. Gaussian curves with σ = 0.977u (FWHM = 2.3) were fitted to the data. Similar results are shown in Fig. 2b for ^{22}Ne as a projectile. Cross sections for the two-proton transfer are in good agreement with ^{18}O, while the small differences in cross section for ^{22}Ne may be due to a slightly higher projectile energy with the ^{254}Es target. We used these extrapolated isotope distributions and a similar method for three- and four-

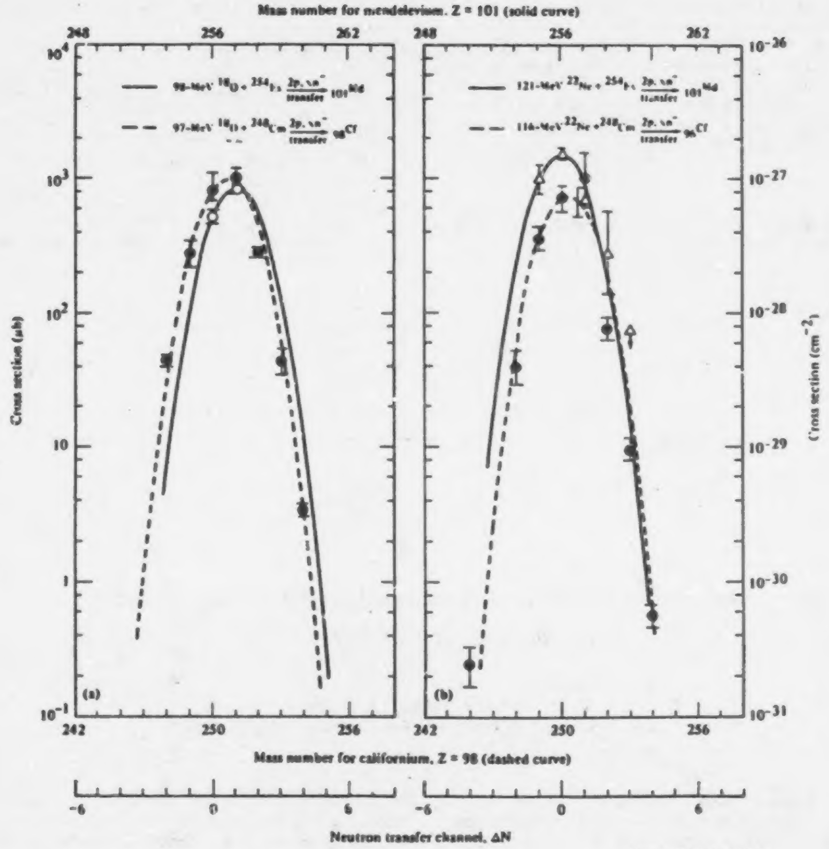

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Fig. 2.
(a) Comparison of two-proton, x-neutron transfer (ΔN) cross sections in the reaction of ^{18}O with ^{248}Cm and ^{254}Es resulting in Cf (dashed curve, lower mass number scale) and Md (solid curve, upper mass number scale) isotopes. Curves are Gaussian with $\sigma = 0.977u$ (FWHM = 2.3)
(b) Same as 2a but with ^{22}Ne as projectile.

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proton transfer to estimate cross sections for unknown neutron-rich heavy actinides. The results are given in Table I. It is important to note that these estimates still contain large uncertainties because we are not yet able to predict the exact Ap position of the isotope distribution. However, it is fascinating to see that exotic nuclei like ^{262}Md or ^{262}Lr should be accessible in reactions of ^{18}O with ^{254}Es.

Footnotes and References

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Table I: Estimated transfer cross sections in μb for unknown neutron-rich actinides.

Reaction	Transfer cross section (μb)						
	^{260}Md	^{261}Md	^{260}No	^{261}No	^{261}Lr	^{262}Lr	Z=104 isotope
^{18}O+^{254}Es	9.	.3	5.	.2	.7	.3	≤.05
^{22}Ne+^{254}Es	.3	≤.05	2.	.1	1.	.2	≤.05

A New 100-ms Spontaneous Fission Activity Abundantly Produced in the Reaction 99 MeV ^{18}O + ^{254}Es

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Numerous authors have shown that the use of transfer reactions between neutron-rich actinide targets and neutron-rich projectiles with A ≤ 22 provides a way to investigate the frontier of very heavy neutron-rich nuclei.[1,2] The Spontaneous Fission (SF) properties of these heavy nuclei, such as half-life and fission mass distribution, are quite interesting to investigate, particularly since the second barrier to fission is predicted to drop below the ground state for some of them.[3] Previous transfer reaction studies have made use of targets up to ^{248}Cm (ref. 1). Using an ^{254}Es target one would hope that even heavier, new short-lived isotopes could be observed.

The neutron-rich projectile ^{18}O was chosen to bombard a small 3-mm-diameter 25-μg/cm^2 ^{254}Es target for this purpose. The target material was produced by irradiating ^{252}Cf with neutrons at the High Flux Reactor (HIFR) at Oak Ridge, Tennessee. Another article by M. Schädel, et al., in this report presents the cross section measurements for production of longer-lived $_{100}$Fm, $_{101}$Md, and $_{102}$No nuclei in the same reaction ^{18}O + ^{254}Es by chemically separating actinide element fractions from recoil catcher foils. To search for short-lived SF emitters with half lives between 10 ms and 5 seconds, we used the recoil tape-transport system with fixed mica track detectors described in the 1977–1978 issue of the annual report.

The decay curve in Fig. 1 shows that a 100-ms SF activity is clearly observed in the reaction 99 MeV ^{18}O + ^{254}Es with a very large production cross section of 1 μb. This cross section is very large compared to the usual nanobarn values measured for other millisecond-lived SF activities.[4] The weighted-average half life from two experiments is 105 ± 7 ms. From the consistency in half-life and production cross-section measurements in separate experiments with tape speeds of 0.2 and 0.9 m/s, tape speed-independent background effects such as neutron-induced fission background can be excluded. The long-lived background that is observed in Fig. 1 is due to production of ^{256}Fm (ref. 2) and ^{256}Md, which decays by electron capture to the 2.6-hour SF emitter ^{256}Fm.

There are indications that a SF activity with a similar half life may be produced in the reaction 73 MeV ^{13}C + ^{254}Es (68–75%)/^{250}Cf (25–32%) with a much lower cross section of ~170 nb, assuming production from the ^{254}Es portion of the target. In the reaction 125 MeV ^{22}Ne + ^{254}Es (63%)/^{250}Cf (37%), cross-section upper limits of 80 nb and 130 nb were established for production of a 100-ms SF activity from ^{254}Es and ^{250}Cf, respectively.

We do not yet know the identity of this 100-ms SF emitter. But ^{261}Lr and ^{261}Md are two candidates consistent with most of our cross-section data and the present understanding of the reactions required to produce these isotopes.[1,2] A 100-ms SF half life for ^{261}Lr, however, creates two interesting problems: (1) SF decay appears to be highly hindered for all other known isotopes of element 103; and (2) this assignment and a possible assignment of ^{262}Rf to a 50-ms SF activity[4] would imply an odd-proton hindrance factor of only 2, compared to at least 10^5 for the similar pairs ^{257}Lr-^{258}Rf, ^{255}Lr-^{256}Rf, ^{253}Lr-^{254}Rf, and a tentative ~10^3 odd-neutron hindrance factor for isotopes of element 104. It seems very likely that one of the tentative assignments ^{262}Rf (50 ms) or ^{261}Lr (100 ms) is incorrect.

A further intriguing possibility is that the 100-ms SF activity reported here might be the same 100±50 ms SF activity produced with a low cross section of 0.5 nb in the reaction 113 MeV ^{22}Ne + ^{242}Pu by Oganessian, et al.[5] The Dubna group has maintained that this 100-ms SF activity is due to ^{260}104 and claimed this SF activity for the discovery of element 104.[6] However, we have not observed an ~100-ms SF activity in other reactions ^{249}Bk (^{15}N,4n)^{260}Rf, ^{248}Cm (^{16}O,4n)^{260}Rf, and ^{249}Cf (^{18}O,α3n)^{260}Rf (ref. 4) in which the production cross sections for ^{260}Rf are predicted to be much higher than in the reaction ^{242}Pu (^{22}Ne,4n)^{260}Rf. ^{261}Lr or ^{261}Md, on the other hand, should have very low production cross sections in the reaction 113 MeV ^{22}Ne + ^{242}Pu, which is not in contradiction with the available cross-section data.

A very promising way to test the possible assignment of ^{261}Lr to a 100-ms SF activity would be to search for 100-ms SF events in the reaction 48.5 MeV ^{10}Be + ^{254}Es. Although a ^{10}Be beam would be radioactive and difficult to obtain, the calculated production cross section for ^{261}Lr is nearly a *millibarn*!

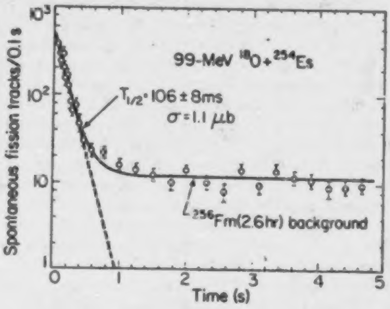

Fig. 1. Decay curve for the bombardment 99 MeV ^{18}O + ^{254}Es (94.6%)/^{250}Cf (5.4%) obtained using the recoil tape-transport system described in the 1977–1978 annual report. The tape speed was 0.2 m/s. See the text for possible assignments for this 100-ms SF activity.

XBL 835-9513

Footnotes and References

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An Upper Limit for Spontaneous Fission Branching in ^{254}No

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The Spontaneous Fission (SF) branching in ^{254}No is an important quantity because it is a measure of the strength of the 152-neutron subshell and its effect on the fission probability of nobelium isotopes. A 152-neutron subshell effect in alpha decay from the ground states of nobelium[1] and lighter elements[2] is well known. In many published SF half-life systematics a partial SF half life is plotted for ^{254}No. However, no actual measurements have been reported in the literature. An upper limit for SF branching of 0.06 percent can be established from the ratio of the upper-limit cross section for SF and the cross section for production of ^{254}No alpha particles in separate experiments by Donets, et al.,[3] and Flerov, et al.;[4] this is plotted in Fig. 1. Knowing only this upper limit, Fig. 1 shows that compared to the SF half lives of other nobelium isotopes a 152-neutron subshell effect is clearly present.

In a recent experiment we thought we had found a SF branch from ^{254}No. In the bombardment 75 MeV ^{12}C + ^{249}Cf a 47±13-s SF activity with a production cross section of ~9 nb was observed. The observation time in this experiment was 65 s; it was therefore difficult to determine whether the half life was 47 s or perhaps longer. A possible SF branch of 0.4 percent determined from these experiments would be consistent with the 14 SF events that decayed with a half life of ~70 s observed by Ghiorso, et al.,[5] in the reactions 197- and 227-MeV ^{48}Ca + ^{208}Pb. However, in another reaction, 72 MeV ^{13}C + ^{245}Cm, an upper limit of 0.05 percent for the fission branch of ^{254}No was established, assuming a calculated production cross section of 1 μb for ^{254}No. This result is in agreement with the upper limit of 0.06 percent established from experiments by Donets, et al., and Flerov, et al.

The origin of the 47-s SF activity is uncertain and will have to be determined in future cross bombardments. The SF branch may still be observable or perhaps an even lower limit may be established from current ^{48}Ca + ^{208}Pb bombardments. A maximum production cross section of 3.4 μb has been measured by Nitschke, et al.,[7] for this reaction.

Footnote and References

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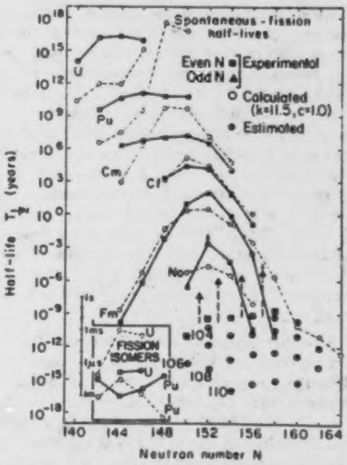

Fig. 1. Spontaneous Fission (SF) half-life systematics for even-even nuclei.[1,6] The half lives for element 104 nuclei are uncertain. Note the upper limit on the partial SF half life of ^{254}No and the extra stability at neutron number 152 associated with a neutron subshell closure.

XBL 756-3150B

Results of Investigations on the New 15- to 24-ms Spontaneous Fission Activities

L.P. Somerville, M.J. Nurmia, A. Ghiorso, and J.M. Nitschke*

In the last annual report[1] Spontaneous Fission (SF) activities with half lives between 15 and 24 ms were reported in the following bombardments: 80 MeV ^{15}N + ^{249}Bk, 92 MeV ^{16}O + ^{248}Cm, 109 MeV ^{18}O + ^{248}Cm, and 96 MeV ^{18}O + ^{249}Cf. The production cross sections for the reactions ^{15}N + ^{249}Bk, ^{16}O + ^{248}Cm, and ^{18}O + ^{249}Cf are consistent with the assignment of an ~20-ms SF activity to ^{260}Rf. Furthermore, an excitation function for the 20-ms SF activity produced in the reactions 78 to 86 MeV ^{15}N + ^{249}Bk was consistent with the shapes of other measured (^{15}N,4n) excitation functions.[2] The measured cross sections for the 15- to 24-ms SF activities produced in the reactions 109 to 119 MeV ^{18}O + ^{248}Cm and 88 to 100 MeV ^{15}N + ^{249}Bk, however, now seem much too high for ^{260}Rf or ^{258}Rf (13 ms) assignments. One hypothesis is that at least two 15- to 24-ms SF activities exist – ^{260}Rf produced in the reactions 78 to 86 MeV ^{15}N + ^{249}Bk and ^{16}O + ^{248}Cm and at least one other nuclide with Z<104 to explain the products of the reactions ^{18}O + ^{248}Cm and 88 to 100 MeV ^{15}N + ^{249}Bk. Within the last year we have performed eleven cross bombardments to try to determine the isotopic assignments that would be consistent with all our data. Table I gives the results of these experiments.

What have we learned? In the reaction 109 MeV ^{18}O + ^{248}Cm the ~20-ms SF activity was again observed. Since the measured cross section is ~50 times larger than that calculated for ^{260}Rf and the measured excitation function is quite broad, this activity is likely to be a transfer product with $Z < 104$. Based on the absence of a 20-ms component when a ^{248}Cm target is bombarded with ^{15}N or ^{13}C ions, it seems unlikely that this product has mass and atomic numbers near the ^{248}Cm target. In the reaction 86 MeV ^{15}N + ^{249}Cf the cross-section upper limit for a possible 20-ms SF activity is only 0.3 nb, or 4% of the calculated maximum ^{249}Cf(^{15}N,4n)^{260}Rf cross section. This cross section is much lower than the cross section of 7 nb reported by Demin, et al.,[3] with 93 MeV ^{15}N ions. ^{260}Rf would be produced in a ^{249}Cf(^{15}N,p3n)^{260}Rf reaction, but the cross section for this reaction is difficult to estimate. We think that a good estimate could be obtained from the cross section for the quite similar reaction ^{250}Cf(^{15}N,p3n)^{261}Rf.

The ~9-ms SF activity produced in the reaction 85 MeV ^{12}C + ^{249}Cf is quite likely due to a mixture of ^{258}Rf (13 ms) and an unidentified 5-ms SF activity, possibly ^{256}Rf (ref. 4). The rest of the cross-section upper limits are in most cases too high to draw any conclusions about the 20-ms SF activities, except that they probably are not due to nuclei near the ^{254}Es or ^{250}Cf targets.

Thus, the hypothesis of at least two 20-ms components is still viable. Up to now, in every case that we expected to produce ^{260}Rf, a 20-ms component was observed. The 20-ms component that was observed in the reaction 109 MeV ^{18}O + ^{248}Cm is probably due to a transfer product with Z<104. If, however, in the future it could be shown that a single nuclide could explain all the 15- to 24-ms components in our data, this activity could *not* be ^{260}Rf.

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Table I

Reaction	Half-Life	Cross Section
109 MeV $^{18}O + ^{248}Cm$	22.4±1.3 ms	10±2 nb
81 MeV $^{13}C + ^{248}Cm$	20 ms	≤6 nb
97 MeV $^{15}N + ^{248}Cm$	20 ms 15 ms	≤1 nb ≤2 nb
86 MeV $^{15}N + ^{249}Cf$	~12 ms 20 ms	≤0.3±0.1 nb ≤0.3 nb
99 MeV $^{18}O + ^{254}Es$	20 ms	≤0.5±0.1 μb
99 MeV $^{18}O + ^{250}Cf$	20 ms	≤1.5±0.3 μb
85 MeV $^{12}C + ^{249}Cf$	~9 ms	5±1 nb
73 MeV $^{13}C + ^{250}Cf$	20 ms	≤370 nb
73 MeV $^{13}C + ^{254}Es$	20 ms	≤150 nb
125 MeV $^{22}Ne + ^{254}Es$	20 ms	≤50 nb
125 MeV $^{22}Ne + ^{250}Cf$	20 ms	≤80 nb

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High Angular Momentum and Gamma De-excitation

Continuum Gamma-Ray Spectroscopy*

R.M. Diamond

When angular momentum is added to a nucleus, it is, of course, carried by the individual nucleons, but two limiting types of behavior may be distinguished: 1) a small number of high-j particles align with the rotation axis and 2) the nucleus is deformed and rotates as a whole. At high spin all nuclei seem to show a compromise utilizing both motions. The excited nuclei left as products of (HI,xn) reactions have so many pathways down that none of the γ-ray transitions have enough intensity to be seen individually until the population gathers near the yrast line. This occurs usually between spin 20–40 $\hbar$. All our information on higher states comes from their continuum spectra. Several general types of techniques are being used to study the continuum.

One recent development is the use of γ-ray multiplicity filters, which involve a number of NaI detectors to determine the number of coincident γ rays per event and thus statistically the γ-ray multiplicity distribution. A high γ-ray multiplicity corresponds in general to a large angular momentum. Because of this relationship, a measurement of average γ-ray multiplicity as a function of γ-ray transition energy gives direct information on transition energy – spin correlations in the continuum. Examples[1] for two target-projectile systems at several bombarding energies are shown in Fig. 1. For ^{40}Ar + ^{124}Sn → ^{164}Er*, there is a pronounced peak in the multiplicity spectrum at all bombarding energies, and it comes at the edge of the bump in the intensity spectrum, corresponding to the highest energy and highest spin transition. This peak moves to higher energy with increasing bombarding energy and, hence, higher angular momentum input. This is a nice confirmation of the collective rotation picture for this nucleus, qualitatively agreeing with the rotational expression,

$$E_\gamma = \frac{\hbar^2}{2\mathcal{J}}(4I-2) \qquad (1)$$

that the γ-ray energy, E_γ, is proportional to the spin, I.

From the γ-ray energy of the multiplicity peaks, combined with the maximum spin (obtained from the maximum multiplicity) for a particular reaction, a value for the moment of inertia can be determined by use of eq. (1). The problem is to get this value for the smallest range in spin possible. Other than with crystal balls, the best way is probably to use a total-energy spectrometer, which yields a FWHM of 60–70$\hbar$ in spin. The idea is as follows: if one can capture in a large NaI counter most of the γ-ray energy emitted in the cascades, one can then make cuts at various excitation energies, hence at various spin ranges, and observe the decay spectrum in a coincident external counter viewing the target through a small hole in the sum spectrometer. Examples of such spectra, taken in a 7.6 x 7.6 cm NaI crystal outside a 20 x 33 cm sum spectrometer and in coincidence with consecutive ~4 MeV wide slices of the total energy, are shown in the next figure[2] for 185 MeV ^{40}Ar + ^{124}Sn → ^{164}Er*. The main products are ^{160}Er and ^{159}Er, well-deformed prolate nuclei in the ground and $i_{13/2}$ bands, respectively, all the way to the highest spins observed. By subtracting one spectrum from the next, we obtain the difference peaks shown at the bottom, which illustrate nicely the increase in E_γ with increase in slice number (excitation energy), and hence spin, as represented by the average multiplicity, M, of the two contributing spectra. Converting M to I (essentially by multiplying by two), we can obtain a value for the effective moment of inertia at that average spin from eq. (1).

This moment of inertia is an "effective" one; it is measured along the average of the γ-cascade pathways and so is an average value for many intersecting (crossing) bands. Another important value is the collective moment of inertia of an individual band. It is smaller and is related to differences between γ-ray energies in the same band and not to the difference between average γ-ray energies in a pathway (several interesting bands). The angular momentum in these excited bands is carried partly by the rotation of the deformed nucleus as a whole and partly by a few high-j nucleons aligned to the rotation axis, j_a. The γ-ray transition energy within the band is then

$$E_\gamma = \frac{\hbar^2}{2\mathcal{J}_{coll}}4(I-j_a) \qquad (2)$$

to be compared with the corresponding form of eq. (1).

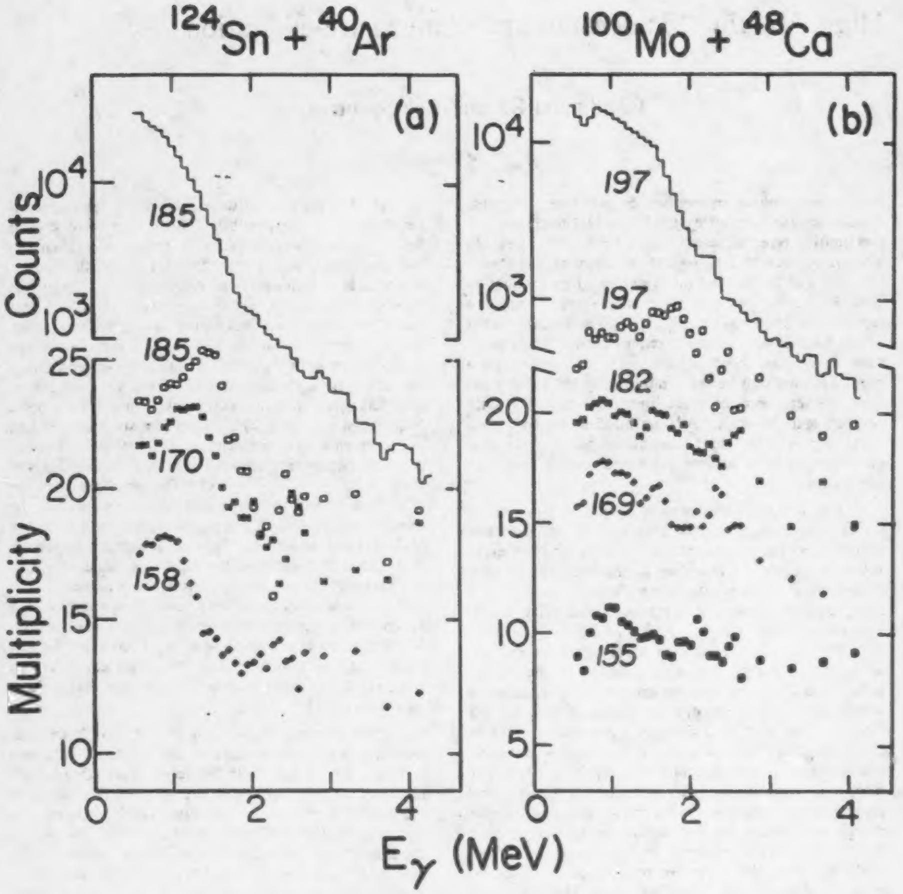


Fig. 1. Plots of multiplicity vs γ-ray energy for the systems (a) ^{124}Sn + ^{40}Ar and (b) ^{100}Mo + ^{48}Ca for the indicated bombarding energies. One NaI γ-ray spectrum is also shown for each system (ref. 1).

XBL 7911-12916

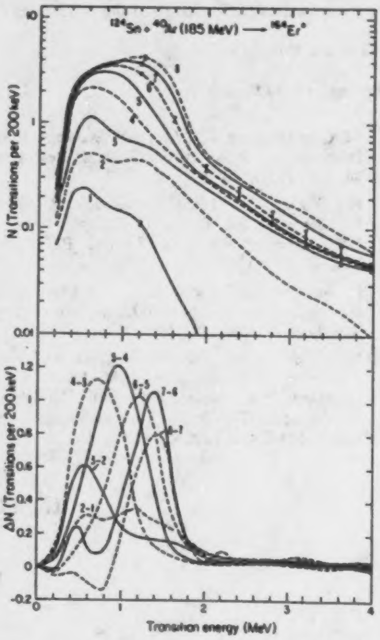
Can $\mathcal{J}_{coll}$ be determined experimentally? There is some evidence that this can be done by studies of γ-γ energy correlations. Consider a nucleus de-exciting through a rotational cascade with a fixed moment of inertia, a true rigid rotor. Then by eq. (1) the γ-ray spectrum is a set of transitions, evenly spaced at $8\hbar^2/2\mathcal{J}$. If this cascade is looked at by two γ counters, and the first one is gated on a particular transition, the coincident spectrum in the second counter is the whole spectrum but for the gated line. Thus in a two-dimensional γ-γ correlation plot there will be a valley along the diagonal, with ridges on each side whose distance apart is equal to $16\,\hbar^2/2\mathcal{J}_{coll}$.

To perform such γ-γ correlation experiments requires good statistics and a method to reduce the number of uncorrelated events. The first successful experiment was made by Andersen, et al.[3] A background of uncorrelated events was subtracted by a statistical method. However, this procedure actually subtracts too many events, including some correlated ones, so that better, iterative methods have been devised. An additional correction to the two-dimensional array is to divide each point by the corresponding relative detector efficiencies.

Such a two-dimensional array (but without the iterated background subtraction or efficiency correction) for the system $^{124}Sn + {}^{40}Ar \rightarrow {}^{164}Er^*$ at 185-MeV ^{40}Ar energy is shown[4] in Fig. 3. Four features, believed to be general, can be pointed out. First, there is a distinct valley along the diagonal up to about 1 MeV (spin $40\hbar$) having a measurable width, and there is some possibility this valley also exists in the region above 1.1 MeV. Second, there are a few bridges across this valley beginning as low as 0.55–0.60 MeV and continuing as far up as the valley persists. Also, there are irregularities in the ridges alongside this valley. Third, there is a general filling of the valley above ~1 MeV, which is rather complete around 1.1 MeV. Finally, on many arrays there are stripes or lines of increased intensity running parallel to the coordinate axes.

The mere existence of the valley strongly indicates the rotational nature of the bands for this range of γ-ray transition energies. In addition, the half-width of the valley is just the difference between successive transition energies, and so determines $\mathcal{J}_{coll}$. The first results on this point suggest that $\mathcal{J}_{coll}$ is indeed smaller than $\mathcal{J}_{eff}$, with values as low as $\sim 0.6\,\mathcal{J}_{eff}$.

The lowest energy bridges in Fig. 3 are due to known backbends in the nuclei produced. The large one at 0.55 MeV ($\omega \sim 0.27$ MeV) corresponds to the first backbends in ^{158}Er and ^{160}Er (the major even-even products). There are at least two more higher energy bridges in Fig. 3. It is not clear which orbitals are involved in these higher bridges. However, the general behavior up to about 1 MeV γ-ray energy seems reasonably clear – a deep valley reflecting good rotational behavior, and a few large irregularities in both the valley and ridge structure resulting from alignment of specific high-j orbitals. Plausible explanations can also be given for the filling in of the valley above 1 MeV and for the existence of the stripes.



XBL 792-645A

Fig. 2.
Top: Spectra from a 7.6 x 7.6 cm NaI detector corrected for the detector response function (number of transitions per 200 keV per event) for consecutive 4 MeV wide slices of the coincident total γ-ray energy spectrum taken with a 33 x 20 cm sum crystal for the reaction products (mainly $^{159,160}Er$) of 185 MeV $^{40}Ar + {}^{124}Sn \rightarrow {}^{164}Er^*$ (ref. 2).
Bottom: the difference in spectra from consecutive slices as indicated in the figure.

XBL 792-645A

The field of continuum γ-ray spectroscopy is a rapidly developing and changing one, and the introduction of new experimental techniques such as the use of crystal-ball, 4π detector systems can only accelerate the pace. Theoretical developments are also proceeding along similarly expanding lines, so that we may look forward to a wealth of new information on high spin and highly excited states in the next few years and much more detailed knowledge about their structure.

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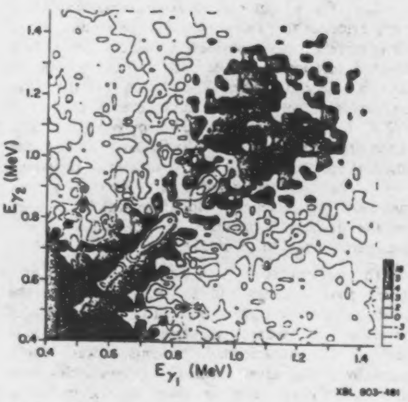

Fig. 3 Energy correlation spectrum from the reaction ^{124}Sn(^{40}Ar,xn)$^{164-x}$Er at 185 MeV. The data were taken with Ge(Li) detectors and had uncorrelated events subtracted. The plot shows contours of equal numbers of correlated events, where the darker regions have more counts according to the scale at the right edge (ref. 4).

XBL 803-481

High Spin States*

F.S. Stephens

Nuclei can generate high angular momentum either by alignment along a common axis of the angular momentum of several individual nucleons or by a collective rotation of the nucleus as a whole. Recent developments in this field have been centered on understanding the competition of these two modes. This can be illustrated in Fig. 1, where level schemes of ^{158}Er and ^{147}Gd are shown[1,2]. The ^{158}Er scheme is quite regular and the dominant behavior is collective rotation of a prolate-deformed nucleus as is illustrated at the left of Fig. 1. The ^{147}Gd scheme is quite irregular, with complicated decay pathways and isomeric states (dark levels). Its dominant behavior is certainly single-particle alignment, as is illustrated at the right of Fig. 1. Yet both of these schemes contain elements of the other type of behavior. There are irregularities in the ^{158}Er rotational pattern at spins around 16 and 26, which correspond to single particle alignments, and the 49/2+ isomer at 8.6 MeV in ^{147}Gd has a quadrupole moment that suggests that the aligned particles are polarizing the core so a collective oblate shape is developing. I will discuss our present understanding of the interplay of these two types of behavior.

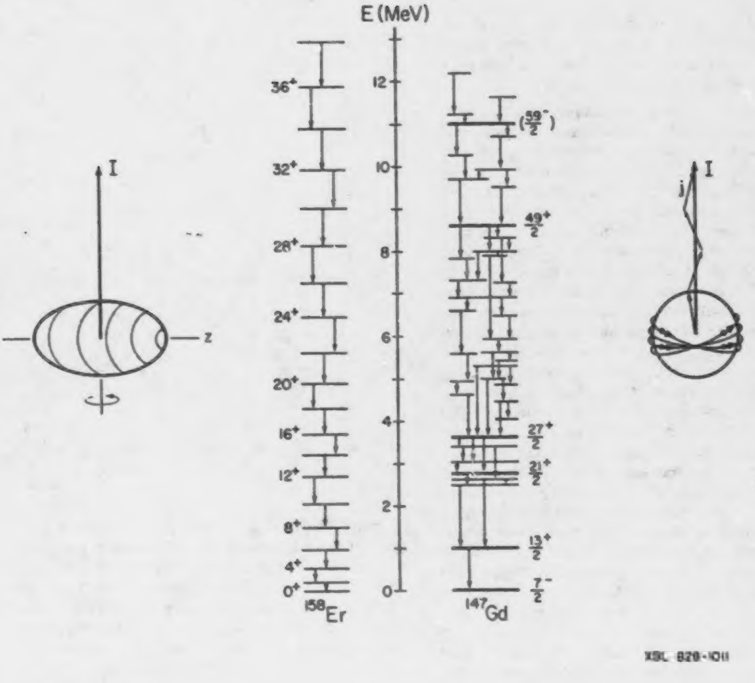

Fig. 1. Level scheme for ^{158}Er and ^{147}Gd, together with illustrations of the dominant source of angular momentum for each case.

XBL 828-1011

One of the most important factors in determining the physics of high-spin states is simply the rotational behavior of rigid classical objects. In Fig. 2 the moment of inertia of such an object is compared with that of a rigid sphere (solid lines) for a variety of shapes and rotational axes. The shape and axis is defined by γ, which varies from $-120°$ to $60°$ as the object varies from a prolate shape rotating about its symmetry axis, through oblate and prolate shapes rotating about axes perpendicular to the symmetry axis, to an oblate shape rotating about its symmetry axis. The deformation is given in terms of a quantity ϵ, which is to lowest order just $\Delta R/R$. Values of ϵ around 0.3 are typical for the familiar deformed rare-earth and actinide nuclei. The largest moments of inertia, and therefore the lowest rotational energies, occur for the range of shapes between $\gamma = 0°$ and $60°$. The very largest moment of inertia is for $\gamma = 60°$, an oblate shape rotating around its symmetry axis, and it is for this reason the earth has such a shape. The full liquid-drop model (LDM) treatment of a rotating nucleus[3] includes volume, surface, and Coulomb energies, in addition to these classical rotor considerations, and is shown by the dots in Fig. 2. It is apparent that there is no strong shape preference in these additional LDM terms, so that simple classical mechanics determine the liquid-drop shapes. This is important, since the liquid-drop model is our best guide to such macroscopic nuclear properties and is even the limit to which some of the microscopic models are normalized.

In order to see how significant these classical shape effects are, one must choose a mass and spin, and for A = 160 and I = 60$\hbar$, an energy scale is given on the right side of Fig. 2. The variation for ϵ = 0.3 of about 10 MeV is larger than typical shell effects (~3 MeV) so that for this spin the effects considered here should be dominant. The rotational energy varies as I^2 so that, for 30$\hbar$, shell effects and these classical shape effects should be about equivalent, and below ~20$\hbar$ the shell effects will dominate. The arguments made here would seem to apply only for collective nuclear rotations, and even then only if the nuclear moment of inertia has the rigid body value, neither of which is obviously the case. In fact, however, most people do believe that rotating nuclei at high spins will, on average, have the rigid-body moment of inertia, and this has been shown to be the case for an anisotropic harmonic oscillator potential and independent particle motion[4]. The smaller moments of inertia observed at low spins are due largely to the pairing correlations, which should be quenched above ~30$\hbar$. Furthermore, even in noncollective cases, it has been shown (for a Fermi gas) that the trajectory of lowest levels follows that given by rotating the appropriately shaped rigid body[5]. Thus, these very simple arguments should be valid, and shapes in the γ = 0–60° range should dominate at high spin, i.e., above ~30$\hbar$ in the A = 160 region. Several types of microscopic calculations have now been carried out for nuclei in this region and all of them agree that the γ = 0–60° range should dominate at high spins, though the models show some differences within the γ = 0–60° range.

A general question arises as to how one can recognize these shapes experimentally. That is, what kind of nuclear structure is expected for shapes in this γ = 0–60° region. It has been recognized since 1952 that a deformed nucleus can rotate collectively around an axis perpendicular to the symmetry axis[6]. The prolate γ = 0° shape is of this type and essentially all the rotational nuclei known have γ-values equal to, or near, 0°. On the other hand, a nucleus cannot rotate collectively around a symmetry axis; those degrees of freedom are contained in the single-particle motion. Thus the γ = 60° oblate nuclei do not have collective rotation, but build up their angular momentum by aligning along a common axis the contribution of various single particles. These are the two basic behaviors discussed above.

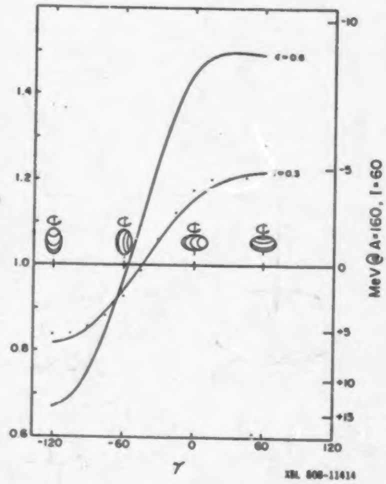

Fig. 2. The ratio of the moment of inertia of a rigid ellipsoid to that of a rigid sphere vs the shape parameter γ for two values of the deformation ϵ = 0.3 and ϵ = 0.6. The right-hand scale gives the difference in rotational energy in MeV for a nucleus with A = 160 and I = 60. The dots give the ratios for the total liquid-drop energy (rotation + surface + Coulomb) of the nucleus.

XBL 808-11414

The kind of structure associated with the triaxial nuclear shapes between γ = 0° and 60° has been elucidated recently – since the first clues to this were found in the backbending phenomenon discovered[7] in 1971. The situation is depicted in Fig. 3. For exactly axially symmetric shapes (upper left) only collective rotation is possible, and different configurations give rise to bands that extend over broad regions of spin. In fact, what is observed to happen is indicated at the upper right, where bands with different configuration have different amounts of single-particle angular momentum aligned with the rotation axis and thereby give rise to slightly nonaxial shapes and a pattern of crossing bands. Sequences with spins up to ~40$\hbar$ have now been observed with three successive alignments (band crossings) that provide about half the total angular momentum of the nucleus. As γ moves closer to 60° (lower left) the proportion of single-particle to collective angular momentum becomes larger, and the rotational bands become less collective with smaller moments of inertia. This situation probably occurs in nuclei like ^{154}Er in the $I = 30\text{–}40\hbar$ region[8] and in ^{154}Dy near[9] $I = 40\hbar$, but is certainly the least documented of the regions of Fig. 3. Finally, at the lower right of Fig. 3, the collective motion is very weak or entirely absent, and we now suspect many nuclei in the $N = 82$, $Z = 64$ region are of this type. So far only ^{147}Gd has quadrupole moments measured to indicate a nonspherical shape[2], but nuclei like ^{152}Dy and ^{150}Gd are very likely of this type. It is not so easy to distinguish these spectra from those of nuclei with spherical shapes, but quadrupole moments can do this, and there may be additional features of the spectra that can help (the rotation about the perpendicular axes). In any case, the main point here is that there are characteristic spectra associated with the shapes between $\gamma = 0°$ and 60°, and these are rather easy to distinguish experimentally. Furthermore, the range of spectral types is (or can be) continuous, as it must be since γ is (or can be) continuous.

It should be recognized that there is no simple path through Fig. 3 along which nuclei evolve with increasing spin. It was clear in Fig. 2 that the $\gamma = 0$ to 60° region was quite flat in the LDM limit so that shell effects determine just where in this range a given nucleus will be. Some nuclei like ^{154}Dy recently discussed by Khoo[9] seem to progress from upper right to lower left and probably on to lower right as the spin goes from 20 to $40\hbar$. However, its neighbor ^{152}Dy shifts from lower-right-type behavior in the $20\text{–}40\hbar$ range to some type (as yet not well specified) of collective behavior at higher spins[10]. The shell effects determine such specific behaviors. However, one generalization we can make is that more single-particle angular momentum generally indicates behavior closer to the $\gamma = 60°$ limit, and conversely a larger fraction of collective angular momentum usually means a shift towards $\gamma = 0°$.

A wealth of experimental data exists to compare with this picture. Below $\sim 35\hbar$ there is generally excellent agreement between the data and detailed shell model-type calculations of these effects; above $\sim 35\hbar$ the data are much less detailed, but seem also to fall into these patterns. Thus, there is a reasonable hope that these simple ideas contain the basic elements of the behavior of nuclei at high spins. There is currently much activity, both experimental and theoretical, to see if that is the case or if there are some important additional features.

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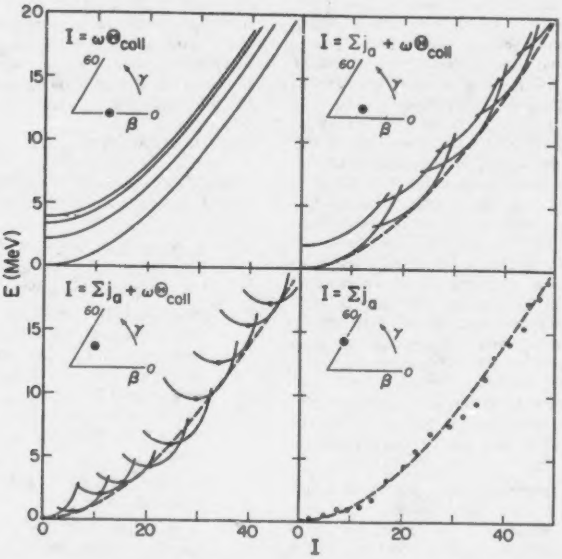

Fig. 3. Schematic excitation energy vs spin plots for various relative amounts of collective angular momentum and single-particle rotation-aligned angular momentum. Bandhead (pure single-particle) energies are shown in the lower two panels. The solid curves correspond to real bands, whereas the dashed curve is the envelope of the real bands.

XBL 804-544

The Rotational Inertia of Nuclei*

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Even rotational nuclei do not rotate like a rigid body. Part of the angular momentum is generated by collective motion, but alignments of single-particle angular momentum on the rotation axis also contribute significantly to the total spin. Such behavior can be described through different moments of inertia: the kinematic moment of inertia $\mathcal{J}^{(1)} = I/\omega$ (where ω is the angular velocity, also called here rotational frequency) describes the overall motion of the nucleus, whereas the dynamic moment of inertia $\mathcal{J}^{(2)} = dI/d\omega$, is related to the response of the nucleus to a torque. When there are changes in nuclear structure (such as alignments), $\mathcal{J}^{(2)}$ will be different from $\mathcal{J}^{(1)}$. $\mathcal{J}^{(2)}$ is a much more sensitive, and therefore more useful, quantity than $\mathcal{J}^{(1)}$.

These two types of moments of inertia can be defined for any sequence of levels; the two most significant ones are $\mathcal{J}_{\text{band}}$ and $\mathcal{J}_{\text{eff}}$ and, in particular, $\mathcal{J}^{(2)}_{\text{band}}$ and $\mathcal{J}^{(2)}_{\text{eff}}$. The collective motion generates bands within which the rate of change in spin with frequency is the moment of inertia $\mathcal{J}^{(2)}_{\text{band}} = (dI/d\omega)_{\text{band}}$. It is accessible at high spins through γ-γ correlation experiments. However, a decay path from a highly excited nucleus at high spin down to the ground state consists of a succession of such bands built on configurations having different alignments, and the rate of change of the total spin with frequency includes both collective motion and alignment effects. It seemed natural to us, therefore, to define a new moment of inertia $\mathcal{J}^{(2)}_{\mathrm{eff}} = (dI/d\omega)_{\mathrm{path}}$. Combined with $\mathcal{J}^{(2)}_{\mathrm{band}}$ values at the same frequency, it should give us a measure of changes in alignment with frequency.

We also recently realized that $\mathcal{J}^{(2)}_{\mathrm{eff}}$ is accessible experimentally (at least in rotational nuclei) through the height of the γ-ray spectrum (density of γ rays as a function of transition energy E_γ). In compound nucleus reactions induced by heavy ions, the continuum γ-ray spectra are detected in NaI scintillators in coincidence with different slices of total γ-ray energy (detected in a sum spectrometer). These spectra sample the decay of different (roughly gaussian) direct populations of states. The value of $\mathcal{J}^{(2)}_{\mathrm{eff}}$ is related to the height of the γ-ray spectrum (normalized to the γ-ray multiplicity). Since, in a rotational nucleus, the transitions are predominantly stretched E2, their number dN is $\simeq dI/2$, and the spectrum height h is $dN/dE_\gamma \simeq dI/4\ d\omega = \mathcal{J}^{(2)}_{\mathrm{eff}}/4$. But h is a measure of $dI/4\ d\omega$ only in the frequency region that is fully populated, i.e., up to about 0.35 MeV.

To obtain $\mathcal{J}^{(2)}_{\mathrm{eff}}$ at high frequency (up to about 0.7 MeV), we devised a way to correct the γ-ray spectra for the feeding. Essentially, the difference of two γ-ray spectra corresponding to slightly different spin feedings (i.e., in coincidence with two consecutive slices of total γ-ray energy) is proportional to the feeding curve $f(\omega)$. Then

$$\mathcal{J}^{(2)}_{\mathrm{eff}}(\omega_0) \propto h(\omega_0)\,\frac{\int_{\omega_{\min}}^{\omega_{\max}} f(\omega)d\omega}{\int_{\omega_0}^{\omega_{\max}} f(\omega)d\omega}$$

Three different rotational systems have been studied at the 88-Inch Cyclotron of the Lawrence Berkeley Laboratory, ^{130}Te + ^{40}Ar, ^{126}Te + ^{40}Ar, ^{124}Sn + ^{40}Ar at 185 MeV. These lead essentially to ^{166,165}Yb, ^{162,161}Yb, and ^{160,159}Er, respectively. The total γ-ray energy was recorded in a sum spectrometer. The γ-ray spectra were recorded in coincidence with the sum spectrometer in seven 12.7 x 15.2 cm NaI detectors, one at 90° to the beam, the others as close as possible to 0° and 180°. For each sum slice, the γ-ray spectra were normalized to their multiplicity. A statistical spectrum was then subtracted and the remaining yrast part was corrected for the feeding and for angular distribution effects.

Figure 1 shows $\mathcal{J}^{(2)}_{\mathrm{eff}}$ obtained for those three systems. In all three cases, the first backbend shows up as a peak, indicating that alignment generates more angular momentum at that frequency. At high frequency, $\mathcal{J}^{(2)}_{\mathrm{eff}}$ increases, starting at $\omega = 0.5$ MeV in Yb nuclei and at 0.6 MeV in Er nuclei. This suggests the alignment of protons, because it is seen at lower frequency in Yb nuclei where the Fermi level is higher. In fact, both larger triaxial deformation (suggested by low $\mathcal{J}^{(2)}_{\mathrm{band}}$ values from correlation data, see Fig. 1) and proton alignment could produce such an increase, and recent calculations by T. Bengtsson and I. Ragnarsson predict that both $h_{9/2}$, $i_{13/2}$ proton alignments and triaxial deformation (around $\epsilon \sim 0.4$) should occur in this frequency range. The crosses in Fig. 1 show predicted $\mathcal{J}^{(2)}_{\mathrm{eff}}$ values deduced from the calculation of spin I as a function of ω for the lowest four trajectories of each parity and signature quantum number in ^{164}Yb. At high frequency, the lower bump is due to proton alignment and the higher one to the onset of triaxial deformation. Those values agree with the experimental results presented, although the latter are more smeared as they represent an average over many decay paths.

The determination of dynamic effective moments of inertia at high frequencies provides some new insights into nuclear behavior at very high spins. $\mathcal{J}^{(2)}_{\mathrm{eff}}$ and $\mathcal{J}^{(2)}_{\mathrm{band}}$ are complementary and are at present the only two moments of inertia measurable in the continuum region. However, the determination of $\mathcal{J}^{(2)}_{\mathrm{eff}}$ at high frequencies is linked to the feeding correction, which is well understood only in rotational nuclei. It will be an exciting challenge to try to explore less collective nuclei in this way. The nuclear properties change gradually when crossing the region of transitional nuclei from mainly collective on the heavier side to mainly single particle on the lighter side.

Footnotes and References

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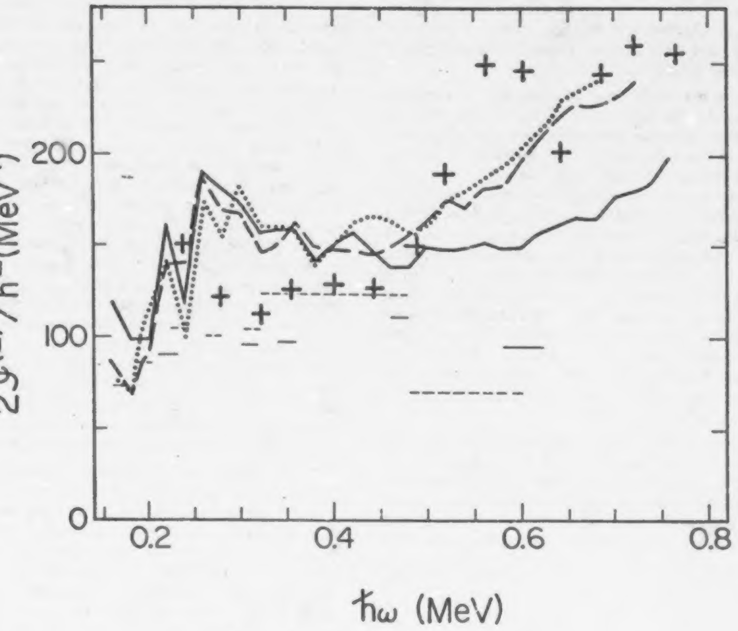

Fig. 1. $\mathscr{J}_{\rm eff}^{(2)}$ as a function of ω for the systems ^{124}Sn + ^{40}Ar (thick solid line), ^{126}Te + ^{40}Ar (dotted line), ^{130}Te + ^{40}Ar (thick dashed line). Also shown are some values of $\mathscr{J}_{\rm band}^{(2)}$ for ^{124}Sn + ^{40}Ar (thin solid lines) and ^{130}Te + ^{40}Ar (thin dashed lines). The crosses are $\mathscr{J}_{\rm eff}^{(2)}$ values for ^{166}Yb deduced from T. Bengtsson and I. Ragnarsson calculations.

XBL 823-233A

Table I

Lifetimes in ps of states in ^{178}Hf and ^{180}Hf.
Average values are compared with rotational model predictions.

Transition	τ(DBLS)ps				τ(Yield)		τ	τ
	E_γ	^{86}Kr Singles	^{86}Kr Coinc.	^{136}Xe Singles	^{136}Xe$^{a)}$ Thick	^{136}Xe$^{a)}$ Thin	(Average)	(Rotat.)
^{178}Hf 6–4	325.6				16.1	16.4	16.2_8	15.0
8–6	426.4	3.96_{11}	4.10_8	4.11_{10}	3.98	3.79	3.99_8	3.86
10–8	512.4	1.55_5	1.35_{10}	1.67_7	1.38	1.45	1.48_5	1.50
12–10	579.7	0.82_3		0.93_5	0.75	0.75	0.81_3	0.78
14–12	626.9			0.65_{14}		0.31	0.48_{10}	0.43
16–14	658.6							
18–16	684.4$^{b)}$							
^{180}Hf 6–4	322.3				14.4		14.4_{10}	13.2
8–6	443.2		3.08_{23}	2.86_{20}	3.50		3.15_{15}	3.07
10–8	546.5		1.17_7	1.20_5	1.06		1.14_5	1.05
12–10	642.0		0.48_9	0.55_6	0.55		0.53_4	0.55

a) Experimental errors are in the range of 5–10% except for the 14^+–12^+ transition, where it is ~25%.
b) Tentatively assigned as the $18^+ \rightarrow 16^+$ transition.

A Third Discontinuity in the Yrast Levels of ^{158}Er*

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J.E. Draper, K.H. Lindenberger, C. Schuck,
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Discrete γ-rays de-exciting states of compound nuclei formed during heavy-ion fusion reactions can give detailed information about the nuclear structure of such high spin states. Although resolved γ-rays from noncollective states have been observed for $I \simeq 38$, for collective states the spins observed are usually below 30.

A study of the high members of the yrast sequence of ^{158}Er was done several years ago[1] when a backbending (attributed to the alignment of an $i_{13/2}$ neutron pair) at $I = 14$ and an upbend (attributed to the alignment of an $h_{11/2}$ proton pair) as high as $I = 28$ were observed.

To study still higher members of the yrast sequence in ^{158}Er, we used the ^{122}Sn (^{40}Ar, 4nγ) reaction with a 170 MeV ^{40}Ar beam at the 88-Inch Cyclotron. Four, self-supporting, thin (0.5 mg/cm^2 each) ^{122}Sn targets were used to insure narrow lines without a reduction in the yield.

Four GeLis were placed in a backward direction, ±(155° to 160°) with respect to the beam so as to minimize Doppler broadening while a fifth GeLi was placed alternately at 0° and 90° for angular distribution measurements.

About 10^8 events (each consisting of a γ-γ coincidence between any two of the five GeLis gated by one or more detectors of a 5-NaI multiplicity filter surrounding the target) were recorded and analyzed. Figure 1 shows after background subtraction the γ-γ coincidence spectra from the four backward GeLis gated by the sum of transitions de-exciting the 18^+-32^+ levels, as well as spectra gated by the three defined highest lines, $34^+ \rightarrow 32^+$, $36^+ \rightarrow 34^+$, and $38^+ \rightarrow 36^+$. From spectra like these, anisotropies (consistent with stretched E2s) and relative intensity determinations, we were able to establish the yrast sequence up to $I = 38$.

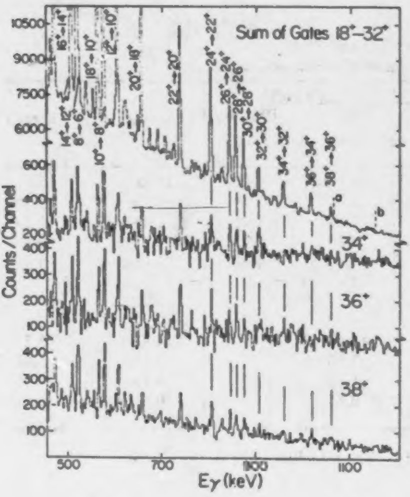

Fig. 1. Coincident γ-ray spectra from ^{122}Sn (^{40}Ar,4n) ^{158}Er obtained with indicated gates.
XBL 8111-1577

In an attempt to find any higher members, 15 weak lines were taken as possible candidates, and the data were sorted in coincidence with these 15 lines. We then looked at the intensity of each yrast line from these spectra (after background subtraction) divided by the intensity of the same line obtained from the sum of gates on transitions from the 34^+, 36^+, and 38^+ levels. If a line feeds the whole yrast sequence from above the 38^+ level, those ratios must be constant up to 32^+ and go above unity for the three higher transitions, because of their suppression in the denominator sum spectrum. Two lines, at 1067 keV and 1155 keV appear to comply with these requirements. We tentatively considered the former to be the most likely $40^+ \rightarrow 38^+$ yrast member.

Figure 2 summarizes the high-spin nuclear structure of ^{158}Er best. The moment of inertia, $2\mathcal{J}/\hbar^2$, total spin I, and the relative aligned spin, i, were plotted[2] vs the rotational frequency $\hbar\omega$. The beginning of a third discontinuity at $\hbar\omega \simeq 0.53$ MeV is suggested. This would imply an alignment with the rotation axes of an additional high-j nucleon pair, thus continuing the pattern for the nucleus to generate its angular momentum partly from collective rotation, partly from alignment of high-j nucleons.

The two $i_{13/2}$ neutrons at the first backbend contribute $10\hbar$ of aligned spin out of a total spin of $16\hbar$ while the two $h_{11/2}$ protons responsible for the second discontinuity contribute $6\hbar$ of aligned spin to a total spin of $28\hbar$. Although the aligned spin is not yet determined, the third discontinuity (at about $I = 40\hbar$) seems most likely to be caused by either $h_{9/2}$ neutrons or $h_{9/2}$ protons, of which the former seem the most likely from calculations.[3]

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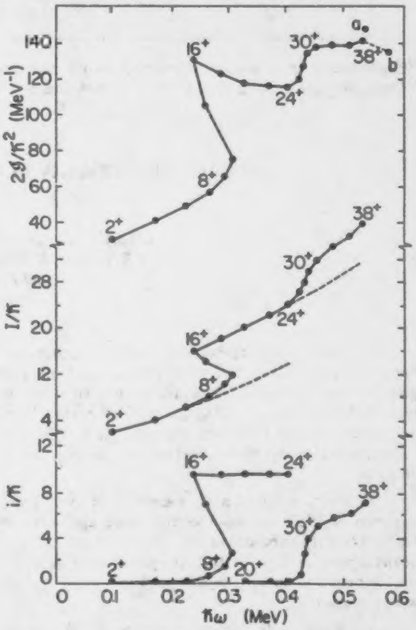

Fig. 2. Plots of moment of inertia (top), yrast spin (middle), and relative spin alignment (bottom) vs the rotational frequency.
XBL 8111-1576

2. Nuclear Reaction Mechanisms

Polarization Studies

The Elastic Scattering of Polarized Protons by ^{40}Ar[*]

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It has been found that the standard optical model analyses of the elastic scattering of medium energy protons from ^{15}N, ^{18}O, ^{24}Mg, ^{40}Ca and ^{40}Ar run into difficulties in fitting the cross-section at the minimum around 140° c.m. and the enhancements at larger angles. Evidence has been found recently for explicit angular momentum dependence of the proton optical model potential (OMP).[1-3] Furthermore, it has been shown that inclusion of an L-dependent potential may in fact solve the problems in the optical model analysis of large-angle scattering at low energies.

Examination of the analyzing powers predicted by the L-independent and L-dependent optical model calculations for ^{40}Ar($\vec{p}$,p) ^{40}Ar elastic scattering at E_p = 32.5 MeV leads to the conclusion that at large angles the effect of L-dependence in the OMP is reflected much more in the analyzing power than in the differential cross-section. Similar observations have been made for proton scattering from ^{16}O at 34.1 MeV.[1] Therefore, analyzing power as well as cross-section data are needed at various energies in order to arrive at more convincing results regarding the L-dependence of the optical model potential.

The purpose of the present work is to provide analyzing power data for ^{40}Ar($\vec{p}$,p) ^{40}Ar scattering at 25.1, 32.5 and 40.7 MeV, complementing existing data at 30 and 50 MeV, and to examine a possible L-dependence of the optical model potential.

Protons with a polarization of approximately 82% were accelerated to the desired energies by the LBL 88-Inch Cyclotron. The target consisted of argon gas contained in a cell at a pressure of 2 atmospheres. Four sets of detector telescopes were used. They were located symmetrically with respect to the incoming beam so that measurements of analyzing power were made at two angles simultaneously. Each telescope comprised a 0.5mm passing detector (ΔE) and a stopping detector (E) with a total depletion depth of 8 mm. The ΔE-E systems were used for particle identification. Collimators defined a geometry factor of 3 x 10^{-6} cm. sr. and provided an angular resolution of ± 0.5° (lab).

The analyzing power measurements at 32.5 MeV are shown in Fig. 1. The curves are optical model fits including L-dependence (full curve), the prediction from the L-dependent fit to the differential cross-sections alone (dash-double-dot curve, an L-independent fit (dashed curve) and the fit obtained from the latter with the addition of an L-dependent term with a strength of V_e = 0.35 MeV (dotted curve). The optical model searches were made with the code SEEK3. The L-dependence included in the calculation is of the form $V_e(-1)^L f(r_e,a_e)$, where $f(r_e,a_e)$ is of Woods-Saxon form.

The inclusion of an L-dependent term improves the quality of the fit to the data, as can be seen in Fig. 1 by comparing the L-independent fit (dashed curve) with the L-dependent result (dotted curve). However, the physical significance of such a term is not yet understood, but may be required to allow for residual effects of the Pauli principle not taken into account by the standard optical potential. The energy dependence of the strength, V_e, of the L-dependent term used to fit our ^{40}Ar(p,p)^{40}Ar elastic scattering differential cross-section and analyzing power data has its largest negative value (-0.92 MeV) near 25 MeV, its largest positive value (+0.33 MeV) near 32.5 MeV, and becomes negligible at beam energies above 45 MeV.

Footnotes and References

[*] Condensed from LBL-15186

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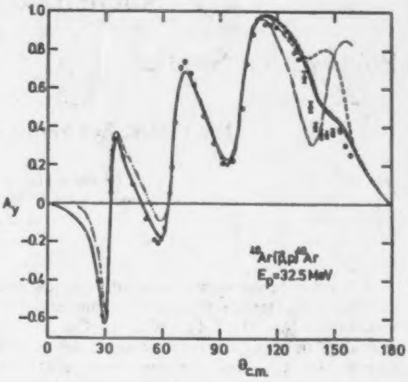

Fig. 1. The analyzing power for $^{40}Ar(\vec{p},p)^{40}Ar$ at 32.5 MeV. Full curve – L-dependent fit, dash-double dot curve – L-dependent prediction from best fit to the cross-sections, dashed line – best fit without L-dependent term, dotted line – best fit with L-dependent term added to the latter potential.

XBL 834-9470

An Experimental Test of Charge Symmetry in n-p Elastic Scattering*

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E.B. Cairns[§], *H. Coombes,*[§] *C.A. Davis,*[§] *P. Green,*[§]
L.G. Greeniaus,[§] *W.J. McDonald,*[§] *G.A. Moss,*[§] *G. Roy,*[§]
J. Soukup,[§] *G.M. Stinson,*[§] *H.E. Conzett, and G.R. Plattner*[††]

Charge symmetry is a consequence of isotopic spin invariance, the first "internal symmetry" that was postulated in elementary particle physics. Isotopic spin invariance is broken by the electromagnetic interaction and consequently one expects effects of the order of the fine structure constant $\alpha = 1/137$. Charge symmetry is a lesser symmetry because it only involves a rotation in isospin space through π. In the case of nucleons, charge symmetry has as a consequence that observables are unaffected by changing neutrons into protons and protons into neutrons. Thus, the neutron-neutron scattering length and effective range are equal to the proton-proton scattering length and effective range after correcting for electromagnetic effects, e.g., the Coulomb interaction. But also, charge symmetry has as a consequence various equalities among neutron-proton scattering spin-dependent obervables, for instance the polarization of the neutron resulting from the scattering of unpolarized neutrons from unpolarized protons equals the polarization of the recoil proton.

Studies of the low energy nucleon-nucleon scattering parameters have shown that charge-independence breaking interactions exist. The neutron-neutron scattering length is greater than the $T=1\,^1S_0$ neutron-proton scattering length or $|a_{nn}| < |a_{np}|$. Such studies do not allow the unequivocal determination of whether charge-symmetry breaking interactions are also present. The main problem is the complicated influence of the electromagnetic interaction in p-p scattering which forbids an unambiguous determination of the purely hadronic parameters.

Charge symmetry of the n-p interaction leads to the complete separation of the isovector and isoscalar parts of the scattering matrix for n-p elastic scattering. In the even (odd) partial waves the isovector part contains spin singlet (triplet) and the isoscalar part spin triplet (singlet) contributions only. The concept of charge symmetry forbids transitions between the two parts of the scattering matrix and thus between the spin triplet and singlet states. the triplet-singlet transition amplitude f_{TS} is thus forced to vanish. This restriction in turn leads to exactly equal polarizations of neutrons and protons in the scattering of initially unpolarized particles. Thus, for a given (neutron) scattering angle θ in n-p scattering, the concept of charge symmetry implies:

Evidence of Time Symmetry Violation in the Interaction of Nuclear Particles*

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P. von Rossen,[‡] *and F. Hinterberger*[‡]

We report here on the first test specifically designed to compare the polarization (P) in a nuclear reaction with the analyzing power (A) in the inverse reaction.[1] We find substantial P–A differences. The clear implication is that time-reversal invariance (TRI) is broken in some component of the nuclear interaction, since the P–A equality follows directly from TRI.[2]

The reactions chosen for the P–A comparison were the two-nucleon transfers ^{7}Li(^{3}He,p)^{9}Be and ^{9}Be(^{3}He,p)^{11}B with 14 MeV incident ^{3}He ions, and their inverses studied at the same CM energies. The Q-values are large, implying considerable mass, energy and momentum rearrangement. The measurements of proton polarizations in (^{3}He,$\vec{p}$) reactions were performed mostly at the Van de Graaff Laboratory of Université Laval, using a facility based on Si-polarimeters, and results have been already published. The analyzing powers in ($\vec{p}$,^{3}He) were measured at the polarized beam facility of the Berkeley 88-Inch Cyclotron. For both the P and A measurements, symmetric left-right geometry was used. This symmetry, along with spin reversal, effectively eliminates systematic errors in the A measurements, and it makes the P measurements insensitive to small transverse displacements of the beam on the target.

Because of (a) the substantial P–A differences in our first measurements, and (b) the significance of this result, we repeated and extended the measurements of A, and we made completely independent checks on the measurements of P. The latter checks were made both at Laval and at Berkeley, with different polarimeters at the two locations. The tests at Laval were twofold. Firstly, some points were remeasured with ^{7}Li and ^{9}Be targets of the same thicknesses as those of the original measurements. The ^{7}Li remeasurements were made with a 500 μ Si polarization analyzer in place of the usual 1000 μ analyzer. Secondly, measurements were made with significantly thinner targets in order to determine the dependence of the polarization on the energy interval spanned in the target. Finally, an overall experimental check was made routinely in the Laval experiments through a measurement of the proton polarization in ^{2}H(^{3}He,$\vec{p}$)^{4}He reaction. The agreement with completely independent meaurements[3] was always within the errors of the separate results.

Our P and A measurements in the ^{9}Be(^{3}He,$\vec{p}$)^{11}B reaction are shown in Fig. 1. Since the ($E_{C.M.}$+Q) energies and the energy widths were not identical for the P and A measurements, an excitation function A(E_p, Θ_L = 37°) was measured in the ^{11}B($\vec{p}$,^{3}He)^{9}Be reaction at an angle near the peak of A(Θ). Over an energy span of some 800 keV, about 400 keV on either side of the original energy, we find a smooth variation of A(E_p). There are no sharp increases in A(E_p) that could move its value into agreement with P under a small shift in the energy.

At Berkeley, a completely different control experiment was possible with the availability of higher energy protons. That is, the ^{9}Be(^{3}He,$\vec{p}$)^{11}B polarizations at Θ_L = 40° and 45° were determined by way of a direct comparison with known ^{12}C(p,$\vec{p}$)^{12}C polarizations. At each angle, measurements were made of the asymmetries ϵ(^{3}He,$\vec{p}$) and ϵ(p,$\vec{p}$) for the polarized protons from the respective reactions. The proton energy in the (p,$\vec{p}$) scattering was selected so that the energy of the protons incident on the polarimeters was the same as those from the (^{3}He,$\vec{p}$) reaction. The latter polarization was then given simply as

$$P(^3\mathrm{He},\vec{p}) = P(p,\vec{p})\,\frac{\epsilon(^3\mathrm{He},\vec{p})}{\epsilon(p,\vec{p})} \qquad (1)$$

Since P=A in ^{12}C(p,p)^{12}C scattering from parity conservation alone, values of A($\vec{p}$,p) can be used in Eq.(1). Although literature values of A(Θ) in ^{12}C($\vec{p}$,p)^{12}C scattering are available near the proton energy used, a separate, high statistics measurement was made of A(Θ) at this energy, E_p = 24.13 MeV. The statistical errors were in the range of $\Delta A = \pm 0.001$ to 0.003, with an additional absolute scale uncertainty of ±2.1% from the beam-monitoring ^{4}He polarimeter. From Eq. (1), then, the P(^{3}He,$\vec{p}$) values were given directly from the ratio of the measured asymmetries and the measured A($\vec{p}$,p) values, and no separate calibration of the polarimeters was required.

Following reports of our preliminary results,[4] independent determinations of P in the ^{9}Be(^{3}He,$\vec{p}$)^{11}B reaction have have been made by a group at Los Alamos.[5] They report a large discrepancy between their preliminary results and our values, with their measurements of P indicating agreement with A in the inverse reaction, as measured by the authors of this letter. Thus, there is now a clear experimental disagreement to be resolved. At the present, however, our lack of detailed knowledge of their experimental procedures precludes an independent evaluation of their results.

In summary, we have found large differences between P in the ^{7}Li(^{3}He,p)^{9}Be and ^{9}Be(^{3}He,p)^{11}B reactions and A of their inverse processes. From such an inequality between P (in a reaction) and A (in its inverse) it is straightforward to conclude that, *prima facie*, TRI is violated in these reactions. Clearly, more experiments are necessary to corroborate these results, and we are pursuing them.

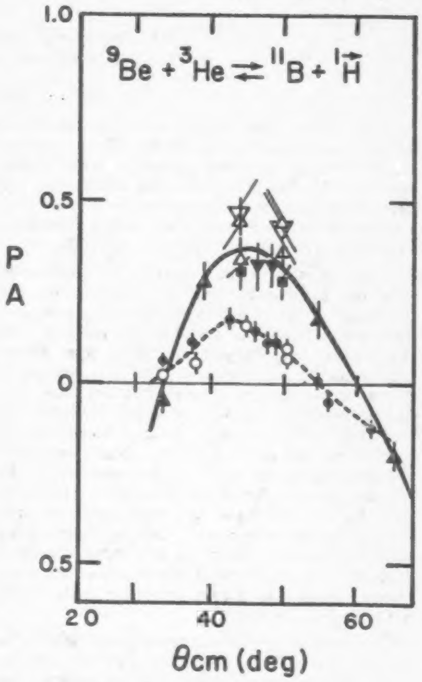

Fig. 1 Comparison of ^{9}Be(^{3}He,$\vec{p}$)^{11}B polarizations with analyzing powers in ^{11}B($\vec{p}$,^{3}He)^{9}Be. The triangles are polarizations measured at Laval, the squares at Berkeley. The dots are the analyzing powers.

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Footnotes and References

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The ^{4}He(α,p)^{7}Li,^{7}Li$^{*(0.478)}$ Reaction Near Threshold*

R. J. Slobodrian[†] *and H. E. Conzett*

The present reaction, leading to the ground state of ^{7}Li, is the inverse of one widely studied since 1933 and was first investigated by Burcham, at al.,[1] at 38.5 MeV. The transition leading to the first excited state of ^{7}Li at 0.478 MeV can only be studied through the α-α reaction. Recent work has been reported by King, et al.,[2,3] mainly related to the astrophysical relevance of the ^{7}Li+p and ^{7}Be+n channels. The present paper is a detailed account of work performed some time ago which has recently motivated short communications in relation to the ^{7}Li and ^{7}Be abundance in the universe and its implications for nucleosynthesis.[3] The analysis of the ^{7}Li+p channel angular distributions is also relevant to the understanding of the elastic α-α scattering in the neighborhood of the opening of reaction channels, and this aspect of the subject was the motive of the investigation. Our results are in good agreement with those of King, et al.,[3] but provide a better mapping of the cross sections very close to threshold.

Differential cross-sections were measured at nine energies between 37 and 43 MeV for transitions to the ground and first excited (0.478 MeV) states of ^{7}Li in the reaction ^{4}He(α,p)^{7}Li. The charged particle spectra were measured with Si(Li) detectors with a resolution of 100 keV for the protons, permitting a complete separation of the groups from the ground and first excited states. The detector pulses were sent to 400 channel pulse height analyzers and to fast scalers, the latter permitting dead time corrections. Such corrections were kept below 1%.

In general, for a reaction

$$A + a \rightarrow C \rightarrow B + b \quad , \qquad (1)$$

where C is assumed to be a compound state of angular momentum J, the angular distribution of the reaction products can be expanded in terms of the sum

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{L} a_k \cos^{2k}\Theta \quad . \qquad (2)$$

If the orbital angular momentum of the initial system is ℓ_1 and that of the final state is ℓ_2 the value of L which gives the highest power of $\cos^2\Theta$ to be found in the angular distribution is given by the minimum value of the set ℓ_1, ℓ_2 and J.[4] The original assumption of Inglis[5] (for the inverse reaction) was that only ℓ=1 and ℓ=3 protons were responsible for the reaction, and ℓ=0 and ℓ=2 alpha particles were emitted. Thus, a good representation of the reaction should be given by expression (2) with k=2:

$$\frac{d\sigma}{d\Omega} = A + B\cos^2\Theta + C\cos^4\Theta \quad . \qquad (3)$$

However, if ℓ=4 alpha particles are emitted (or feed the ^{7}Li+p channels in the inverse reaction) it is necessary to consider an additional term D $\cos^6\Theta$. The data at 39.94 MeV show a clear improvement of the fit with D $\cos^6\Theta$. The energy region where the $\cos^6\Theta$ term is important is sharply defined in energy. This was borne out subsequently and independently by the phase shift analysis of the α-α angular distributions where, due to the evidence provided by the cross sections of the ^{7}Li+p channels, absorption was included in the ℓ=4 partial wave. In the notation $\delta_\ell = \alpha_\ell + i\beta_\ell$, where δ_ℓ is the scattering phase shift, β_4 is a measure of the absorption of the ℓ=4 partial wave. It peaks sharply at 19.72 MeV (energy in the center of mass) and is sizeable only over a region of 0.5 MeV. The need to include a term in $\cos^6\Theta$ has also been established independently by King, et al.[3] Figure 1 shows the cross sections for ^{7}Li^{GS}+p and ^{7}Li$^{*0.478}$+p and their sums compared to results by Burcham, at al.,[1] and King, at al.[3] Such cross sections were obtained by integrating the angular distributions of protons at each energy.

The main result obtained from the study of the α+^{4}He $\rightarrow$ ^{7}Li+p, ^{7}Li$^{*0.478}$+p reactions was, historically, independent evidence for the presence of absorptive effects in partial waves with $\ell \geq 4$ in the entrance channel. The present interest is mainly astrophysical.[3] The complete determination of the problem posed by the interaction of alpha particles above threshold for particle reactions requires the investigation of all open channels, and even *closed channels* with thresholds near a given energy region. King, at al.,[3] have made measurements at a few points near threshold in the α+^{4}He -> ^{7}Be+n, ^{7}Be$^{*0.431}$+n channels by capture of the radioactive ^{7}Be recoils and subsequent counting of the decay γ rays. A more complete investigation could be pursued either by neutron detection or by the identification of the ^{7}Be recoils in a ΔE-E detection system. Such systems have been developed and used in heavy ion reaction studies at energies as low as 1 MeV/A, thus the 16.8 to 16.9 MeV energy of the ^{7}Be recoils at threshold, due to the CM motion, is clearly sufficient for direct detection. The total reaction cross section as a function of energy, is another observable capable of providing additional constraints for a formal description of the reaction and its determination is also desirable. The reactions with a *totally symmetric initial state* (space, spin and charge) and charge symmetric final states are ideal testing grounds for charge symmetry and its violations. Increased accuracy is certainly possible in these studies, both experimentally and theoretically.

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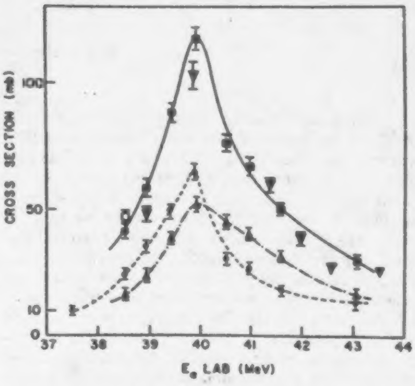

Fig. 1. Cross sections for the proton channels: ^{7}Li+p is given by dots, ^{7}Li$^{*0.478}$+p is given by upright triangles. The sum of both channels is shown by solid squares for the work reported here, the open square is taken from ref. 1, the inverted triangles from ref. 3. There is good overall agreement. The lines are polynomial fits to the data.
XBL 834-9471

The Radiolysis and Racemizaton of Leucine on Proton Irradiation*

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Previous experiments have been done by ourselves and others to test the Vester-Ulbricht (V-U) hypothesis[1] for the origin of optically active molecules in nature through the attempted asymmetric radiolysis of racemic amino acids, using natural or artificially produced antiparallel longitudinally polarized beta particles. As an extension of this work, we[2] have recently subjected DL-leucine to partial radiolysis instead with longitudinally polarized protons of both parallel and anti-parallel spin. Reasons have been given to advance the idea that polarized protons might be more effective than polarized electrons for engendering such asymmetric effects. Nevertheless, we were unable to detect any enantiomeric inequality in the undecomposed DL-leucine residues – even when such radiolyses were completed to 47–50% – with protons of either spin polarity, either when they passed completely through the leucine samples or were stopped by them.

After our discovery[3] that ionizing radiation could cause the racemization of amino acids accompanying their radiolysis, we suggested that such radioracemizaton must inevitably diminish the effectiveness of the V-U mechanism for engendering optical activity by asymmetric radiolysis. In particular, it was pointed out[4] that if the rate of radioracemization were greater than the rate of asymmetric radiolysis, it is possible that no enantiomeric inequality might be produced in the undecomposed residue after partial radiolysis. It was later suggested[5] that such effects might be responsible for the lack of asymmetric degradation noted by Hodge, et al.,[6] during radiolysis of DL-leucine with longitudinally polarized electrons.

In none of the attempted asymmetric radiolyses mentioned above, using either natural or artificially produced longitudinally polarized electrons, has a systematic attempt been made to assess the actual importance of competing radioracemization or of secondary degradative reactions in a particular experimental system, although it has been noted that negligible radioracemization accompanied the 25–30% gross radiolysis of solid D- and L-leucine with ^{32}P beta particles at –196°. Accordingly, further experiments seemed desirable to evaluate the potential importance of these factors in our recent unsuccessful attempts to induce optical activity in DL-leucine by irradiation with polarized protons.[2]

We have conducted four irradiations of D- and L-leucine at the 88-Inch Cyclotron under conditions previously employed for irradiations of DL-leucine.[2] In the present experiments, however, the use of longitudinally polarized protons was unnecessary, and unpolarized protons of the same 0 – 11 MeV energy range were utilized. The leucine sample disks (129 mg) were irradiated as D- and L-pairs, again alternating each pair between variable and fixed aluminum absorbers in the proton beam, such that the beam passed through the first sample disk and was stopped by the second. Beam intensities were about 14 namps and irradiation times were 144 – 147 minutes, such that the measured integrated beam total was 120 microcoulombs. Since the energy loss in each sample was 5 MeV/H^+, each sample received a dose of ~5 x 10^8 rads.[2] After irradiation two of the samples were quenched immediately by dissolving in a hot 4.5 M solution of HCl in 2-propanol. Half of each solution was treated with the appropriate "enantiomeric marker" of the original D- or L-leucine to determine percent degradation, and the resulting mixtures were converted to N-trifluoroacetylleucine isopropyl ester derivatives for gas chromatographic (g.c.) analysis for enantiomeric composition. The g.c. analyses were conducted using columns loaded with the enantiomeric g.c. phases N-docosanoyl-D-valyl- (D-phase) or N-docosanoyl-L-valyl-*tert*-butylamide (L-phase). The remaining two samples were allowed to stand at room temperature for 21 days, then were dissolved, divided, and \similarly converted to N-TFA isopropyl ester derivatives for g.c. analysis. Both D- and L-phase g.c. columns were used for the g.c. analyses of each sample in order to provide a "symmetry check" and to disclose any systematic errors that might be inherent in the experiments or analyses. The results of these experiments are shown in Table I. At the outset Table I shows overall good agreement in both degradation and racemizaton results for each experiment using either the D- or L-phase g.c. columns, indicating no systematic errors in the experiments. We also note that the amount of racemization of the leucine engendered by 5 x 10^8 rads irradiation with the proton beam is rather low (1.1–1.7%) compared to that observed during γ-radiolysis,[4] and does not vary appreciably if the beam passes through the sample or is absorbed by it, or if the sample is derivatized immediately after irradiation or after 21 days. The L-leucine pair samples are consistently about 10%, less degraded than the corresponding D-leucine samples (Expts. 1 vs 3, and 2 vs 4), which is probably due to uncontrolled parameters in the proton beam intensity. The degradation caused by the higher energy protons passing through each first leucine sample in the beam, however, is consistantly 5–5.5% higher than that that caused when the lower energy protons are fully absorbed by the second sample in the beam (Expts. 1 vs 2, and 3 vs 4), suggesting that the average energy deposited in the first sample was about 5% higher. Finally, at least in the present type of experiment, the data in Table I make it appear improbable that our failure to observe asymmetric radiolysis of DL-leucine at 50% degradation with longitudinally polarized 0 – 11 MeV protons[2] was attributable to competing radioracemization or to secondary (symmetrical) degradation effects.

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Table I
Degradation and Racemization of D- and L-Leucine on Irradiation with 0–11 MeV Protons

Exp.	Leu-cine	Beam[a)]	Days[b)]	D-Phase Column					L-Phase Column				
				%D	%L	(±)[c)]	% Deg	% Rac	%D	%L	(±)[c)]	% Deg	% Rac
1	L	PT	0	0.87	99.13	.05	44.1	1.7	0.85	99.15	.11	44.9	1.7
2	L	A	21	0.82	99.18	.03	38.8	1.6	0.76	99.24	.06	39.4	1.5
3	D[d)]	PT	21	99.47[e)]	0.53[e)]	.01	54.9	1.1	99.20[e)]	0.80[e)]	.13	54.8	1.6
4	D[d)]	A	0	99.34[e)]	0.66[e)]	.05	49.9	1.3	99.18[e)]	0.82[e)]	.01	49.8	1.6

a) A = Beam absorbed in sample; PT = Beam passed through sample.
b) 0 = Sample derivatized immediately after irradiation; 21 = Sample derivatized after 21 days.
c) Standard deviation of 3–4 analyses.
d) Contained 0.36% L-Leu.
e) Corrected for L-Leu content of original D-Leu.

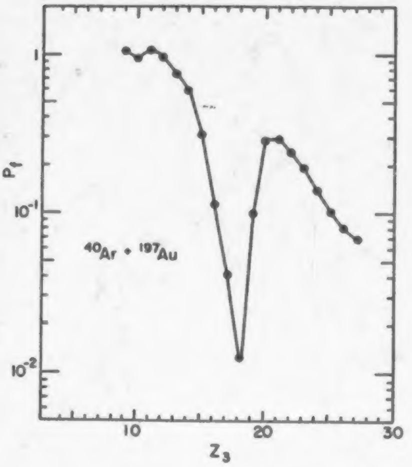

Fig. 1. The fission probability as a function of projectile-like fragment Z integrated over energy is shown.

XBL 833-8959

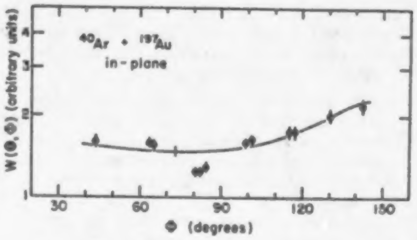

Fig. 2. The in-plane distribution of sequential fission fragments from the reaction of ^{40}Ar + ^{197}Au is shown. This angular distribution shows a significant anisotropy in the rest frame of the recoiling nucleus indicating a preferential direction for the fragment angular momentum.

XBL 833 8960

Compound Nucleus Decay Via the Emission of Large Fragments

L.G. Sobotka, M.L. Padgett, G.J. Wozniak, G. Guarino,
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We have studied the emission of α, ^{6}Li, ^{7}Li, ^{7}Be, ^{9}Be, B, C, and heavier fragments in the reaction 130 MeV ^{3}He + ^{nat}Ag at the 88-Inch Cyclotron. The intermediate mass fragments were detected using a set of three standard gas-solid state ΔE-E telescopes. Alpha particles were detected in a separate solid-state telescope (40 μm, 5 mm). Angular distributions were obtained from 20° to 170° in the laboratory.

A beam of ^{3}He was chosen because it produces a compound nucleus with high excitation energies and because the products of projectile fragments are lighter than the products of interest.

The energy spectra in the center-of-mass system are shown in Fig. 1. The spectra shift to higher energies as the ejectile increases in charge; however, the rate of increase is slower than a simple Coulomb calculation would predict. The spectral shapes also evolve from a Maxwellian for α-particles to a shape far more symmetric fo the heavier ejectiles.

From 100° to 180° the angular distributions (not shown) range from flat to slightly backward peaked. This slight backward peaking is expected from angular momentum considerations. At more forward angles the cross sections increase and the spectra become harder. This might be due to an incomplete subtraction of events caused by target impurities or the presence of some forward focused nonequilibrium process. Nevertheless, at angles >100° the spectral shape is independent of angle. This fact, along with the shape of the angular distributions in the backward hemisphere, confirms that these backward data are due to an equilibrium decay process.

These data are being interpreted in terms of both standard evaporation and fission (transition state) formalisms.

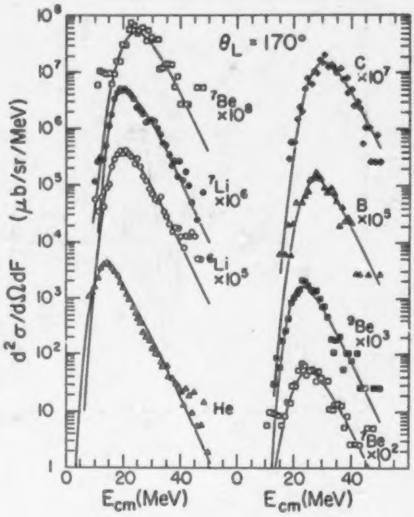

Fig. 1. Center-of-mass kinetic energy spectra for various ejectiles in the reaction 130 MeV ^{3}He + ^{nat}Ag.
XBL 827-874

Footnotes

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Intrinsic Fragment Spins Generated in the Reactions of ^{20}Ne with ^{197}Au and ^{238}U at 12.6 MeV/Nucleon[*]

D.J. Morrissey,[†] G.J. Wozniak, L.G. Sobotka, A.J. Pacheco,[‡] R.J. McDonald, C.C. Hsu,[§] and L.G. Moretto

Experimental techniques used to obtain the magnitude and alignment of the transferred spin include α-particle, γ-ray, and sequential fission fragment angular distribution measurements. The out-of-plane angular distributions of γ rays and sequential fission fragments are primarily sensitive to the average random spin component. The angular distributions of γ rays and α-particles are rather insensitive to differences in the in-plane projections of the random spin component. In contrast, the angular distributions of sequential fission fragments are quite sensitive to such differences in that they can produce a substantial in-plane anisotropy.

Values of the aligned spin $<I_z>$ and the thermal widths were extracted from the sequential fission fragment angular distributions obtained for the reaction of 252 MeV ^{20}Ne with ^{197}Au and ^{238}U. The extracted values of $<I_z>$ are plotted versus Q-value in Fig. 1 for both the ^{20}Ne + ^{238}U and the ^{20}Ne + ^{197}Au systems. For the former system, $<I_z>$ increases steadily with Q-value. A similar increase of $<I_z>$ with Q-value has been observed in several other reaction systems. Because of the high fission barriers for nuclei near Au, values of $<I_z>$ were obtained only for the most negative Q-values of the ^{20}Ne + ^{197}Au reaction. A striking difference between the two systems is the much larger values of $<I_z>$ observed for the ^{20}Ne + ^{197}Au relative to the ^{20}Ne + ^{238}U system. Since the ℓ_{max} and the rigid rotation partition for the two systems are very similar, the difference most likely reflects the strong bias towards high spin states for the fissioning gold nuclei and the absence of such a bias for the fissioning uranium nuclei. This bias is intoduced by the large fission barrier for gold nuclei.

The values of the aligned spin $<I_z>$ and the thermal widths extracted from the fitting of the sequential fission fragment angular distributions can be used to determine the two alignment parameters P_{ZZ} and P_{XY}. The results for P_{ZZ} and P_{XY} obtained from the fitting of the fission fragment angular distributions for the uranium system are shown in Fig. 2. In contrast to the strong Q-value dependence observed in more symmetric systems (cf., e.g., Refs. 1-3) the extracted values of P_{ZZ} are approximately constant at 0.8 for the ^{20}Ne + ^{238}U system. The in-plane alignment parameter shows a stronger dependence on Q-value. It is positive at small Q-values and then goes to negative values at larger Q-values.

The predictions of the statistical equilibrium model for two touching spheres (solid curves in Fig. 2) lie substantially below both the P_{ZZ} and P_{XY} data. Although this discrepancy could be interpreted as indicating that the dinuclear system is not at equilibrium (with respect to the normal modes), a more likely explanation is that the present model of two touching spheres does not allow for either deformation or interfragment separation (neck formation). Indeed, there is extensive evidence for large deformations of the nuclei at their scission configuration following a deep inelastic collision[4,5]. A first order estimate of the effect of deformation in the model calculations can be made by allowing the target-like fragment to deform along the line-of-center of the dinuclear system. Model calculations of P_{ZZ} and P_{XY} are shown in Fig. 2 for different ratios of axes (C/A) of the target-like fragment. Both P_{ZZ} and P_{XY} are quite sensitive to the deformation of the heavy fragment. In this calculation, σ_x and σ_z increase slowly whereas σ_y decreases rapidly with increasing C/A. Thus increasing C/A causes P_{ZZ} to increase because the random component of spin decreases while the aligned component is constant. P_{XY} approaches zero as C/A increases because σ_y becomes similar to σ_x. In this model, a ratio of axes of 1.6 to 2.0 is needed to reproduce the data in the deep-inelastic Q-value region. Such deformations of the heavy fragment are consistent with values given by the equilibrium configuration of a rotating sphere-spheroid liquid drop model system.[4]

Footnotes and References

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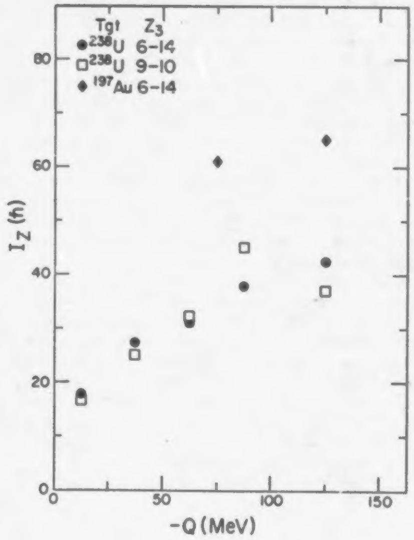

Fig. 1. The measured aligned spin (I_z) of the target-like fragment as a function of Q-value for the 252-MeV ^{20}Ne + ^{197}Au and ^{238}U reactions. Spins were extracted for a broad Z-bin (6–14) for both systems and an additional narrow one (Z = 9–10) for the ^{20}Ne + ^{238}U system. The statistical errors are of the same size or smaller than the symbols.

XBL 822-4472

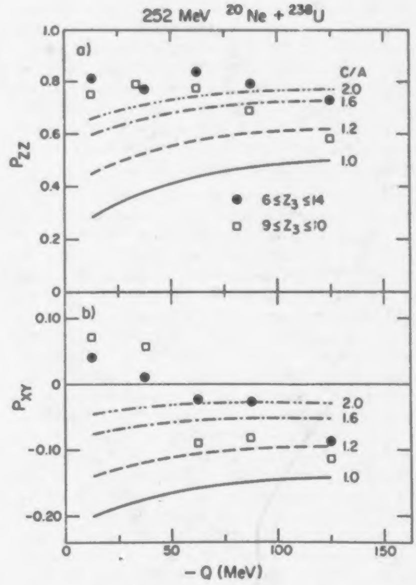

Fig. 2. The measured alignment parameters for the spin distributions obtained for the ^{20}Ne + ^{238}U system are shown for Z = 6 to 14 (circles) and Z = 9 and 10 (squares). The solid and dashed curves represent the statistical equilibrium model calculations for different ratios of axes (C/A) of the target-like fragment (see text).

XBL 821-4417

A Study of ^{20}Ne Induced Reactions with ^{nat}Cu and ^{197}Au at 8.6 and 12.6 MeV/nucleon*

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B. Cauvin,[§] *R.P. Schmitt,*[**] *J.S. Sventek,*[††]
and L.G. Moretto

Calculated mean lifetimes for the ^{20}Ne + ^{197}Au reaction are shown in Fig. 1 as a function of incident ℓ-wave. Results are presented for calculations with and without neck formation. The bifurcation into the neck and no-neck curves occurs as soon as the trajectory for the system reaches the critical distance. Clearly, the inclusion of the neck has a dramatic influence on the lifetime distribution for both systems by displacing the critical ℓ-wave for trapping of the ion-ion complex to higher incident angular momenta. This increases the complete-fusion cross section substantially. It is interesting that for the ^{20}Ne + ^{197}Au reactions no complete fusion is predicted in the absence of a neck, whereas substantial complete fusion is predicted when a neck is allowed to form. Since the data seem to display a substantial fusion-fission component, this is perhaps an indication of the importance of neck formation. The complete fusion events are treated here according to the method outlined in Ref. 1.

In Fig. 2 experimental and calculated angular distributions are shown for representative fragment Z-values both above and below the projectile. It should be noted that these calculated angular distributions have not been normalized. In fact there is only one free parameter in these calculations, which is the ratio of the variance of the reaction lifetime to its mean value, σ^2/τ. Changing this variable adjusts the slope of the angular distributions for atomic numbers near the projectile. A value of $\sigma^2/\tau = 0.20$ yielded the best fits for the ^{20}Ne + ^{197}Au reaction. The model calculations have not been corrected for charged-particle evaporation, which may have shifted these data by as much as one to three charge units.

The trends observed in the data are present in the calculations (see Fig. 2). It is particularly satisfying that the side peak in the 175-MeV ^{20}Ne + ^{197}Au data emerges from the model calculations. It is also interesting that the flattening of the distribution at backward angles is less pronounced in the ^{20}Ne + ^{197}Au data. This is predicted by the model simply because for higher ℓ-waves the fragments do not penetrate deeply enough to form a neck, which would increase the collision lifetime. Nevertheless, for a large range of ℓ-waves a neck eventually does form (see Fig. 1) leading to a symmetric compound-nucleus fission component in the charge distribution similar to that observed in the data.

Footnotes and References

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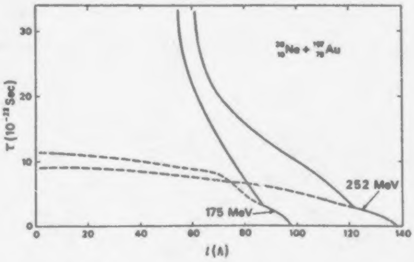

Fig. 1. Calculated average diffusion lifetimes as a function of incident ℓ-wave for the ^{20}Ne + ^{197}Au reactions.

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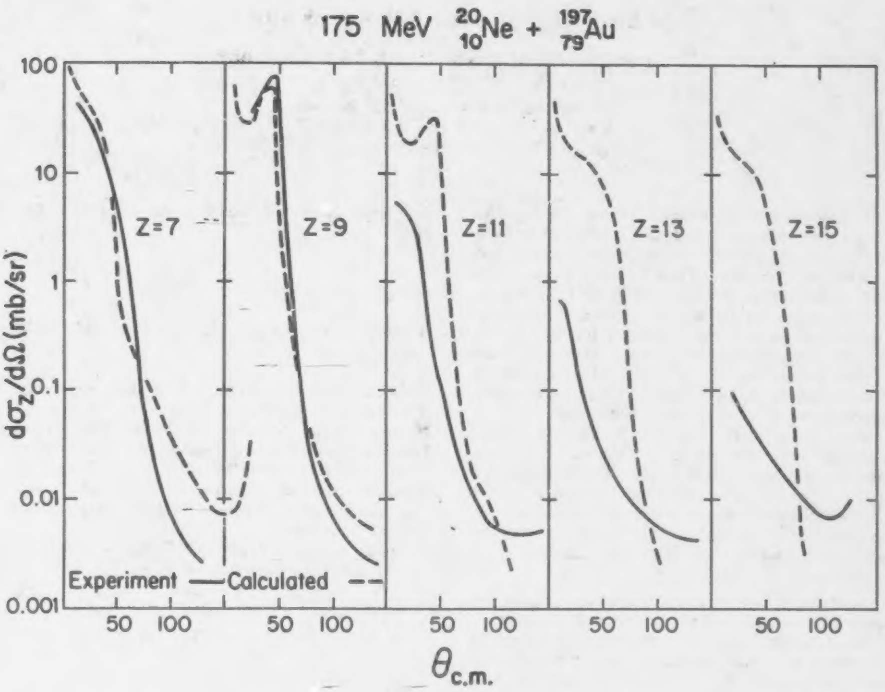

Fig. 2. Calculated and experimental angular distributions for representative products for the ^{20}Ne + ^{197}Au reactions.
XBL 798-2439

1253

The Onset of Non-Equilibrium Phenomena in Fusion-Like Processes for ^{16}O Induced Reactions[*]

Y. Chan, M. Murphy, R. G. Stokstad, I. Tserruya[†],
S. Wald, and A. Budzanowski[‡]

At bombarding energies not too far above the interaction barrier, the complete fusion of heavy ions to form an equilibrated-compound nucleus comprises a dominant part of the total reaction cross section. Further increase of the bombarding energy induces reactions which approximate fusion but exhibit non-equilibrium features. In such cases, it is generally believed that only a part of the projectile or target fuses with the other partner (incomplete fusion), while the remaining part is emitted, presumably at an early stage of the collision and prior to the thermalization of the composite system.

Previous studies of these non-equilibrium features have emphasized the observation of forward-peaked, fast light particles (n,p,d,α) with velocities near to or greater than the beam velocity, sometimes in coincidence with the residual-like fragments. It follows that the onset of incomplete fusion should also be reflected in a reduced average velocity of the associated heavy residues. (We consider only mass-asymmetric systems with the projectile as the lighter partner.) The present experiments determine the average velocity (or the linear momentum) of the residues, which are then compared with evaporation model predictions. Deviations of the observed velocity centroid and/or spectrum shape may be interpreted in terms of reaction mechanisms other than complete fusion followed by equilibrium decay.

The experiments were performed at the 88-Inch Cyclotron at ^{16}O bombarding energies of 8.8, 13.6, and 19.6 MeV/u. The energies were chosen to cover the region where one expects to see predominantly complete fusion (8.8 MeV/u) as well as regions where non-equilibrium phenomena can be important (13.6, 19.6 MeV/u). Conventional time-of-flight techniques were used to measure the velocity of the residual nuclei. Natural calcium, aluminum, and ^{60}Ni targets with thickness of 235, 215, and 180 μg/cm^2, respectively, were used. Masses up to about 50 amu could be resolved (Fig. 1a).

For decay processes symmetric about 90° in the rest frame of the emitter, the velocity dependence of the quantity $F(v) \equiv (1/v^2)d^2\sigma/dvd\Omega$ is expected to be a Gaussian centered at $V_{cm} \cos \Theta$, where v is the velocity of the residues in the laboratory, Θ is the laboratory detection angle, and V_{cm} is the velocity of the center of mass.[1] Fig. 1b shows a spectrum of $N(v)/v^2$, which is proportional to F(v), for residues of mass 43 detected at 5° for 13.6 MeV/u ^{16}O + ^{40}Ca.

We find that the quantity $\bar{v}/\cos\Theta$ depends only weakly on the residual mass or the scattering angle. The deviations of this quantity from V_{cm}, averaged over all masses and angles, increase with bombarding energy. The results obtained with ^{27}Al and ^{60}Ni targets exhibit the same qualitative features.

In the following we shall concentrate on the observed angle- and mass-averaged velocity centroids, which we express as a percentage of the velocity corresponding to full momentum transfer followed by equilibrium decay. This quantity is plotted in Fig. 2 vs. the relative velocity of the colliding partners at the interaction barrier (r_0 = 1.5 fm). Even though there is some dispersion in the data, an apparent systematics is seen to emerge; the amount of transferred momentum, expressed as a percentage of the total available linear momentum, is governed essentially by the relative velocity of the projectile and target nuclei at the barrier. Within errors, the deviations of the average centroids from the predictions of full momentum transfer appear to be independent of the target, suggesting that the missing momentum is mainly associated with the ^{16}O projectile.

The data also exhibit an approximately linear behavior in the decrease of the fraction of transferred momentum as a function of velocity as is suggested by the straight line fit to our data points. A similar result has been reported by Viola, et al.,[2] for reactions involving heavier targets. These results suggest a common onset of incomplete momentum transfer in fusion-like reactions at about 5 MeV/u above the interaction barrier. For comparison, also included in Fig. 2 are the results of ref. 3 obtained from fission fragment correlation measurements using ^{16}O projectiles and a much heavier ^{238}U target. Except for the highest energy point, which lies two standard deviations above the fitted line, these results are consistent with our systematics, and, together, suggest that the relative velocity of the projectile and target at the interaction barrier is a relevant parameter for characterizing incomplete linear momentum transfer in fusion-like processes. The data shown in Fig. 2 are consistent with there being little or no dependence of the missing momentum on the mass of the target. These simple results, if validated by additional experiments on a wider range of targets, should prove valuable in the evaluation of theories of pre-equilibrium emission or incomplete fusion.

We appreciate the help of M. Blann in various stages of this experiment.

Footnotes and References:

[*] Condensed from LBL-15187; submitted to Phys. Rev. C.

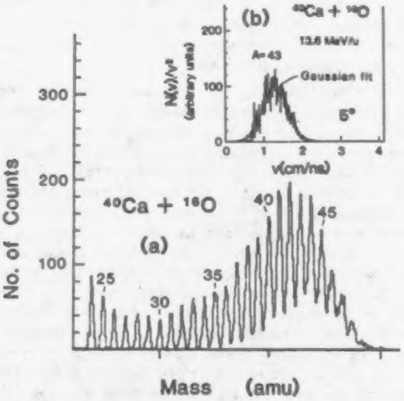

Fig. 1
(a) Partial mass spectrum for ^{16}O + ^{40}Ca at E_L = 13.8 MeV/u and Θ = 5° (lab).
(b) $N(v)/v^2$ spectrum for A = 43. N is the number of counts per unit velocity interval. The curve is a Gaussian fit to the spectrum.

XBL 829-11496

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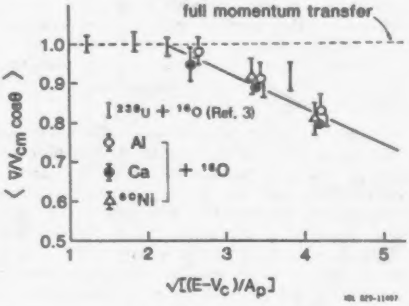

Fig. 2. Systematics of the mean velocities of fusion-like residues, expressed as a percentage of the velocity corresponding to complete momentum transfer. The abscissa is the relative velocity of the projectile and target at the interaction barrier (r_0 = 1.5 fm). The energy E and Coulomb barrier V_c are evaluated in the laboratory system.

XBL 829-11497

1255

Momentum Widths of Heavy-Ion Reaction Products at 27.4 MeV/n[*]

Martin J. Murphy[†] *and Robert G. Stokstad*

The inclusive momentum spectra of ejectiles emitted at forward angles in heavy-ion reactions exhibit a characteristic "quasi-elastic" (QE) peak. This peak has a mean velocity approximately equal to the beam velocity, and is observed for laboratory bombarding energies of 5 to 2000 MeV/n. We report here an inclusive measurement at 27.4 MeV/n, and discuss the status of the currently available body of similar data.

We have measured energy spectra for the reactions, ^{9}Be+Au → ^{6,7}Li+X. A 246 MeV ^{9}Be beam from the 88-Inch Cyclotron was used to bombard a 3.25 mg/cm^2 natural Au target. A Si(Li) particle telescope with elements 87 μm, 500 μm, and 5mm thick, located at $\Theta_{lab} = 12°$, was used to detect and identify reaction products. All of the different ejectile isotopes were resolved and complete energy spectra for ^{6}Li and ^{7}Li were obtained. The energy spectra for ^{6}Li and ^{7}Li are shown in Fig. 1. A Gaussian momentum distribution in the projectile rest frame was transformed to a laboratory energy distribution and used to fit the QE peak. The fitting region encompassed the peak and the high energy side and avoided the low energy tail. The fitted curves are also shown in Fig. 1, along with the resulting centroids and momentum widths. The energy centroids correspond approximately to the beam velocity. We obtained values for the reduced momentum width, σ_0, of 65.4 ± 2.9 MeV/c and 60.2 ± 1.2 MeV/c for ^{6}Li and ^{7}Li, respectively, where[1]

$$\sigma^2 = \frac{A_F(A_P - A_F)}{A_P - 1}\sigma_0^2 \quad . \qquad (1)$$

Fig. 2 is a summary of several measurements of σ and σ_0 at various energies. It includes the results of Egelhaaf, et al.,[2] the high energy points at 213 MeV/n and 2.1 GeV/n,[3,4] the data of Scott, et al.,[5] reanalyzed by Harvey,[6] and our new measurement at 27.4 MeV/n. In all cases the widths are for the total momentum distributions at the grazing angle and are obtained from the energy spectra of single isotopes. The fits in each case cover the apparent quasi-elastic part of the energy spectrum. (At energies below 50 MeV/n this region excludes the obvious low energy tail. At higher energies, where no low energy tail is evident, the fit extends over the full spectrum.) The measurements at 213 MeV/n and 2.1 GeV/n provided widths for a large number of different isotopes. Rather than plot all of the individual points, we have indicated the full ranges of observed widths, as well as the mean values.

The data compiled in Fig. 2 show a similar energy dependence for both σ and σ_0. The transition from the low to the high energy limit is not as abrupt as originally suggested,[5] but it is fully realized over the energy range of 10-200 MeV/n. The factorization according to eq. 1 reduces the mass dependence at most energies, but leaves a residual mass dependence in σ_0 that is more pronounced below 100 MeV/n than at higher energies. The limited amount of data available at energies below 100 MeV/n makes more quantitative statements on the mass dependence of σ_0 difficult.

One must be cautious when using the data for σ_0 (E) in Fig. 2 as evidence for or against the occurance of particular reaction mechanisms (e.g., fragmentation, breakup, transfer, etc.). In particular, the data below 100 MeV/n suffer from several problems which affect the interpretation of σ and σ_0. For instance, all of the results summarized in Fig. 2 have been obtained from inclusive measurements of the reaction spectra. A variety of reaction mechanisms could be represented in these spectra, each contributing its own isotope and energy dependence to the total width. For example, it is known that both transfer and breakup reactions occur at the lower energies.[7] Secondly, the available data below 100 MeV/n only provide the width of the total momentum distribution. There is evidence[8] that below 200 MeV/n only the longitudinal momentum dispersion has the mass dependence of eq. 1. As a final point, we note that the fitting procedure to obtain σ is itself quite subjective. It requires assumptions about the effect of the low energy tail and qualitative decisions about the part of the spectrum to be included in the fit. Even among the data presented here there are certainly systematic differences due to these necessary judgements.

In conclusion, our measurement of quasi-elastic momentum widths at 27.4 MeV/n yields results that support a relatively smooth transition in the reduced width σ_0 between 10 and 200 MeV/n. Upon reexamining all of the similar data available at energies from 5 to 2000 MeV/n, we have noted that this transition is just as evident in the "unreduced" width σ. There are problems with the interpretation of σ_0; it not only conceals a known anisotropy in the longitudinal and transverse momentum dispersions, but also a variety of reaction mechanisms. Therefore, any conclusions about the reaction dynamics at low energies, based upon the presently known values of σ_0, are premature. The reliable deduction of physical information from measurements of σ_0 at low energy must await the systematic measurement of each momentum component and separation of the inclusive spectra according to reaction mechanism.

We would like to thank Karl Van Bibber and Peter Countryman for discussions and assistance with the measurements.

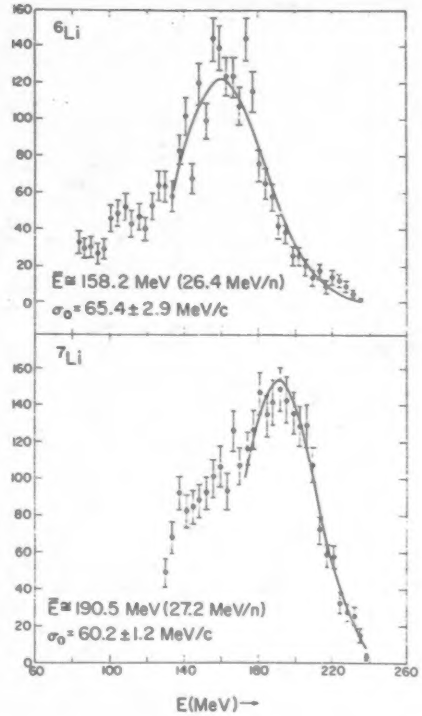

Fig. 1. The inclusive laboratory energy spectra for ^{6}Li and ^{7}Li ejectiles from ^{9}Be+Au at 27.4 MeV/n. The solid curves are fits to the quasi-elastic parts of the spectra.

XBL 827-1593

Footnotes and References

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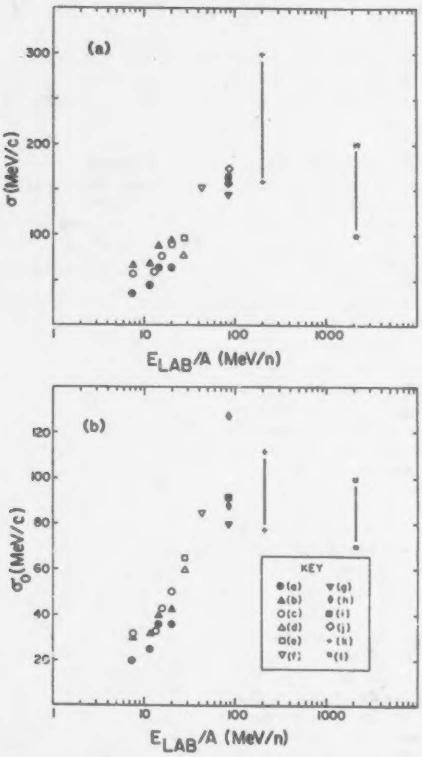

Fig. 2. A compilation of several different measurements of the momentum widths σ and the reduced momentum widths σ_0 of ejectiles from heavy ion reactions. The key to the reactions is

a) ^{197}Au(^{20}Ne,^{16}O), ref. 2
b) ^{197}Au(^{20}Ne,^{12}C), ref. 2
c) ^{208}Pb(^{16}O,^{12}C), ref. 6
d) ^{nat}Au(^{9}Be,^{7}Li), This work
e) ^{nat}Au(^{9}Be,^{6}Li), This work
f) ^{181}Ta(^{20}Ne,α), ref. 9
g) ^{12}C(^{12}C,^{6}Li), ref. 10
h) ^{12}C(^{12}C,^{7}Li), ref. 10
i) ^{12}C(^{12}C,^{7}Be), ref. 10
j) ^{12}C(^{12}C,^{10}B), ref. 10
k) ^{232}Th(^{40}Ar,X), ref. 3
l) ^{16}O+X ref. 4

A large number of widths were measured at 213 and 2100 MeV/n; the figure indicates the range and mean value of the results.

XBL 829-9684

Observation of Symmetric Disintegration in the ^{6}Li, ^{9}Be, ^{12}C + ^{40}Ca Reactions

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I. Tserruya, S. Wald, G. Guarino, D. J. Morrissey,
L. G. Sobotka, G. J. Wozniak, and L. G. Moretto

During the last decade fission-like phenomena have been studied for a number of medium-A systems.[1] This work is intended to test predictions of the liquid-drop and related models in the region A ~ 50 where experimental data are scarce. At the 88-Inch Cyclotron coincident fission-like products were observed in reactions induced by ^{6}Li, ^{9}Be and ^{12}C projectiles on a ^{40}Ca target. The energy and charge of the reaction products were measured with ΔE-E telescopes.

Figure 1 shows coincidence count rates measured at equal telescope angles, $\Theta_1 = \Theta_2$, for symmetric reaction products with $Z_1 \simeq Z_2$. Keeping one of the detectors at the angle Θ_2 corresponding to the maximum in Fig. 1, and varying the position of the other detector produces the correlation functions shown in Fig. 2. These functions reflect the kinematics of secondary fragments remaining after evaporation of nucleons and alpha particles by primary binary fragments. The correlation function found for ^{12}C + ^{40}Ca at 121 MeV has a FWHM about 10% smaller than the value at 186 MeV. An angular correlation function measured out of the reaction plane at 186 MeV has about the same width as the in-plane function.

For the ^{12}C + ^{40}Ca reaction, singles angular distributions were measured with ΔE - E telescopes at six incident energies between 74 MeV and 186 MeV. Fig. 3 presents a center-of-mass angular distribution at 186 MeV for fragments with Z = 11. The 1/sin Θ dependence indicates that a compound system was formed. Assuming a 1/sin Θ dependence for all angles, the total cross section for the disintegration into two fragments of comparable mass, σ_{fission}, has been calculated and yields the following values: 18.8 mb for ^{12}C + ^{40}Ca at 186 MeV; 4.0 mb for ^{9}Be + ^{40}Ca at 140 MeV; and 1.2 mb for ^{6}Li + ^{40}Ca at 153 MeV. For ^{12}C + ^{40}Ca at 186 MeV, the above value of σ_{fission} agrees well with a prediction of the dynamic coalescence and reseparation model of Swiatecki.[2,3]

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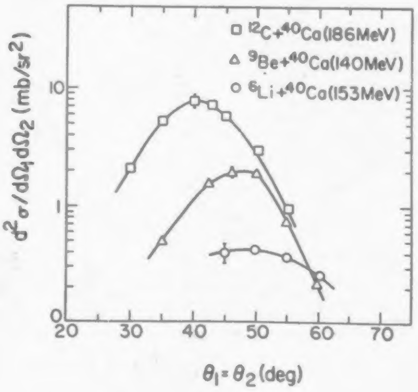

Fig. 1. Coincident count rates measured at equal telescope angles for symmetric reaction products with $Z_1 \simeq Z_2$.

XBL 835-2617

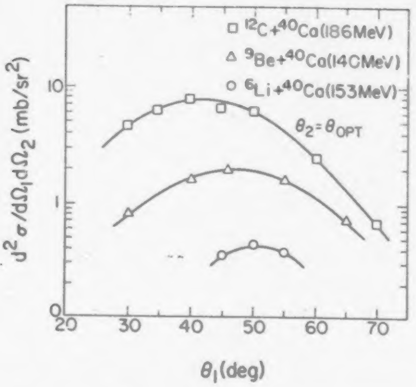

Fig. 2. Angular correlation functions for symmetric reaction products: one telescope is fixed at the angle of the maximum in Fig. 1.

XBL 835-2616

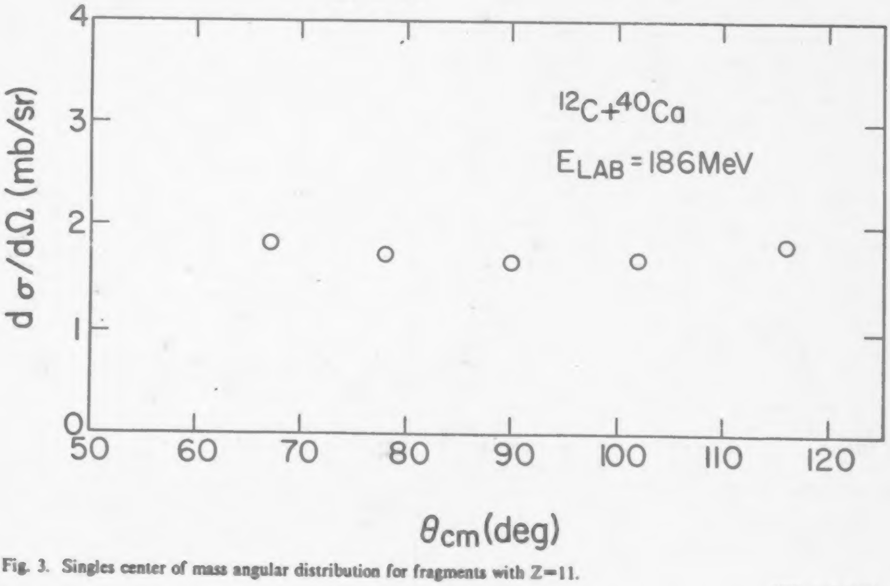

Fig. 3. Singles center of mass angular distribution for fragments with $Z=11$.

XBL 835-2618

$^{12}C^*$ and ^8Be Production in $^{12}C + ^{208}Pb$ Collisions*

A.N. Bice,[†] A.C. Shotter,[‡] and Joseph Cerny

This report presents results of an investigation at the 88-Inch cyclotron into fast α-particle production via the production of ^{8}Be(g.s.), ^{8}Be(2.94 MeV), and excited ^{12}C reaction products from the $^{12}C + ^{208}Pb$ system at ^{12}C bombarding energies of 132, 187, and 230 MeV. Absolute cross sections have been obtained for the reactions $^{208}Pb(^{12}C, ^{12}C^* \rightarrow \alpha + ^8Be)$, ^{208}Pb(^{12}C,^{8}Be(g.s.)), and ^{208}Pb(^{12}C,^{8}Be(2.94 MeV)) by coincident measurement of three α-particles or two α-particles for $^{12}C^*$ and ^{8}Be detection, respectively. By folding in the probability of detecting correlated particles, the absolute production cross sections were determined, which were then compared with the measured singles α-particle cross section at 187 MeV ^{12}C bombarding energy. From this comparison, further information could be obtained about the reaction channels important in fast α-particle production.

A detection system was employed which consisted of three ΔE-E counter telescopes mounted on a movable platform and arranged in a vertical fashion with respect to the normal scattering plane. A pair of particle telescopes were located symmetrically above and below the scattering plane, i.e., the collimator post between these two telescopes was bisected by the horizontal reaction plane. Further, a third telescope was always located above the reaction plane. Coincidence events between any pair of telescopes were recorded, but simultaneous events in all three were not.

Figure 1 shows a Wilczynski-type diagram for ^{8}Be(g.s.) production at 187 MeV. Such a diagram plots contours of the double differential cross section $d^2\sigma/d\Omega dE$ for the ^{8}Be(g.s.) reaction products as a function of their kinetic energy and their laboratory scattering angle, highlighting both the energy and the angular distributions. This figure and those at the other bombarding energies show a ridge near beam velocity that extends from the maximum toward backward angles. There is little or no evidence of a ridge extending back from zero degrees as is characteristic of a deep inelastic reaction. The ridge is therefore likely to be associated with an interaction that is peripheral in nature. No other significant features are evident.

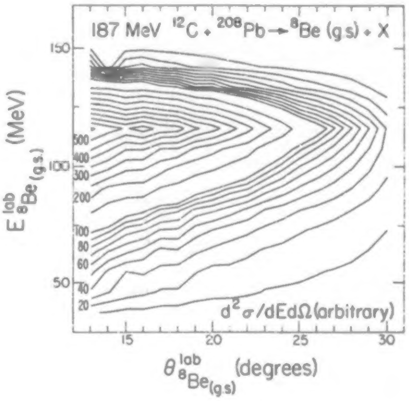

Fig. 1. Wilczynski-type diagram for the production of ^{8}Be(g.s.) nuclei for the system 187 MeV $^{12}C + ^{208}Pb$.
XBL 8110-7361

Figure 2 shows the absolute differential cross section for the production of ^{8}Be(g.s.) nuclei. These cross sections were obtained by integrating the (^{12}C,αα) spectra by energy bins with the appropriate detection probability for ^{8}Be(g.s.) nuclei folded in. Increasing cross section with decreasing angles and steeper angular distributions with increasing bombarding energy are evident in this figure. Cross sections to several hundred millibarns are apparent, suggesting that a significant fraction of the inclusive α-particles arise from decaying ^{8}Be nuclei.

The observation of a large production cross section for ^{8}Be(g.s.) and ^{8}Be(2.94 MeV) nuclei at E(^{12}C) = 187 MeV permits the conclusion that projectile fragmentation is largely responsible for the fast α-particle production. These measurements, together with those of Siwek-Wilczynska, et al.,[1,2] provide an explanation for the origin of over 80% of the observed α-particles at 187 MeV bombarding energy. Although the observed ^{8}Be production cross sections as a function of the bombarding energy are not in disagreement with the simple incomplete fusion model predictions of Siwek-Wilczynska, et al., it is also clear that projectile spectroscopic and/or final state interactions are important in fragmentation reactions at these bombarding energies. An angular correlation measurement of $\alpha + {}^8$Be reaction products would be feasible and very valuable to a further understanding of the breakup mechanism(s) involved.

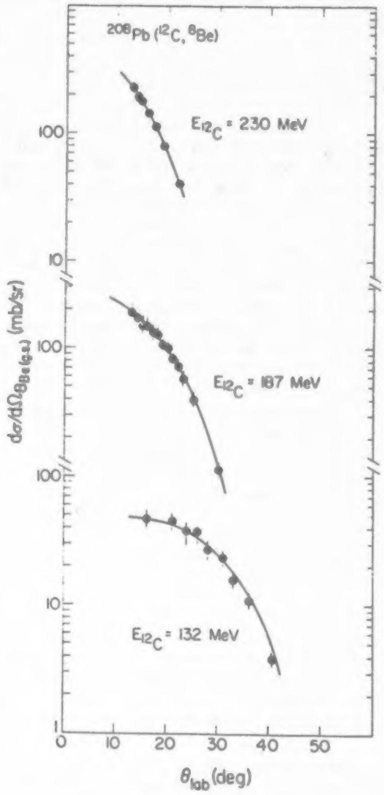

Fig. 2. Angular distributions for the production of ^{8}Be(g.s.) nuclei for the system ^{12}C + ^{208}Pb at three ^{12}C bombarding energies; 132, 187, and 230 MeV.

XBL 818-1161

Footnotes and References

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Transfer and Breakup Reactions in ^{16}O + CsI at 16.4 MeV/n*

M.J. Murphy, B.G. Harvey, D.L. Hendrie, W.W. Pang, K. Van Bibber,† and R. Legrain‡

A streamer chamber triggered by any one of three Si(Li) particle telescopes at 12.5°, 17.5°, and 24.0° (lab) was used to observe the multiplicity of charged particles in coincidence with the trigger particle in the reaction ^{16}O + CsI at 16.4 MeV/nucleon. The measurement provided relative probabilities for transfer and projectile breakup as a function of ejectile charge, as well as energy spectra of the heavy ejectiles from transfer and breakup events. The events were photographed by a single camera in the direction normal to the reaction plane defined by the beam and the trigger particle. Simultaneously, the signals from the ΔE-E telescope were recorded on magnetic tape along with an event number identifying the photographic frame.

The photographs were scanned for charged particle multiplicity in the forward and backward hemispheres. The positions of the projectile track at the target and of the ejectile track at the chamber exit window were checked for consistency with the target center and the telescope position. Because of the high level of RF noise from the Marx generator, only Z-identification was obtained from the telescope for $Z = 3$, 5-8. At $Z = 4$, ^{7}Be and ^{9}Be were well resolved.

We assume that tracks in the backward hemisphere arose from charged particle evaporation from the target and that evaporation was isotropic in the laboratory system. The numbers of forward hemisphere events were corrected for the (small) evaporation contribution and summed over telescope angles. The resulting multiplicity distributions are shown in Table I.

We interpret multiplicity (M) = 1 events as transfer reactions and $M \geq 2$ events as projectile breakup. Table I shows that $Z = 7$ ejectiles are produced almost exclusively by the transfer mechanism and that the ratio of breakup to transfer increases with decreasing Z. Nevertheless, a nine nucleon transfer produces most of the ^{7}Be. A striking result is that (except for Li triggers) multiplicities (M) greater than two are very rare. This observation alone places some restrictions on the mechanism of projectile breakup, suggesting that sequential decays of excited ejectiles play a major role.

As an example, most of the $M = 2$ events with $Z = 5$ are due to ^{11}B. A prompt ^{16}O fragmentation would produce ^{11}B + ^{5}Li. But ^{5}Li is unstable to decay to ^{4}He + p, so this mechanism could not give an $M = 2$ event. On the other hand, the sequences $^{16}\text{O} \rightarrow {}^{12}\text{C}^* \rightarrow {}^{11}\text{B} + p$ or $^{16}\text{O} \rightarrow {}^{15}\text{N}^* \rightarrow {}^{11}\text{B} + {}^{4}\text{He}$ would yield ^{11}B in $M = 2$ events. Moreover, the prompt $M = 2$ breakup of ^{16}O into ^{9}Be + ^{7}Be would produce equal yields of these nuclides, whereas we observed 4.5 times more ^{9}Be than ^{7}Be. A sequence such as $^{16}\text{O} \rightarrow {}^{13}\text{C}^* \rightarrow {}^{9}\text{Be} + {}^{4}\text{He}$ could contribute to the extra ^{9}Be yield in $M = 2$ events.

The energy spectra both of transfer and breakup reactions show the familiar quasi-elastic peak at an ejectile velocity close to projectile velocity. However, the peak energies of the breakup spectra, as shown in Table II, are shifted down in energy by 10 – 20 MeV. The energy shifts in $M \geq 2$ spectra are just what would be expected for transfer reactions (or inelastic excitation of ^{16}O) that leave the primary ejectile at an excitation energy just above the theshold for ^{4}He or p decay. The small (9 Mev) shift for $Z = 6$ triggers is, on this picture, due to the low (7.2 MeV) threshold for $^{16}\text{O}^* \rightarrow {}^{16}\text{C} + {}^{4}\text{He}$.

Table I. The associated charged particle multiplicities, summed over angle after correction for target evaporations. Also included is the total number of observed backward-going tracks for each ejectile charge.

	MULTIPLICITY					
EJECTILE	1	2	3	4	5	N_{BACKWARD}
Li	22	60	17	5	0	25
^{7}Be	11	4	5	0	0	3
^{9}Be	40	18	1	1	0	11
B	66	45	2	2	0	12
C	194	85	4	1	0	7
N	339	16	1	0	0	0

Footnotes

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Recoil Range Studies of Target-like Products of Multinucleon Transfer from ^{18}O to ^{245}Cm and ^{249}Cf

Rose Marie McFarland, Albert Ghiorso, and Glenn T. Seaborg

Our group is interested in knowing the mechanism, or mechanisms, contributing to the production of nuclides of Z and A between those of the target and compound nucleus in reactions of actinides with light heavy ions (LHI) ($4 < A \leq 40$) at energies just above the interaction barrier. In this preliminary study,[1] measurements were made of recoil ranges of alpha and spontaneous fission activities produced in bombardments of ^{245}Cm and ^{249}Cf with ^{16}O projectiles.

All bombardments were done at the 88-Inch cyclotron at Lawrence Berkeley Laboratory. The targets consisted of 0.240 mg ^{245}Cm/cm^2 and 0.520 mg ^{249}Cf/cm^2 as the actinide trifluoride. Curium-245 was bombarded with 93, 99.6, and 111.6 MeV ^{18}O and ^{249}Cf with 83, 89.2, 99.8, and 111.6 MeV ^{18}O projectiles. Recoiling products were caught in a stack of ten 0.1 mg/cm^2 aluminum foils. After a bombardment, each foil was placed over a Si(Au) surface barrier detector with pulse height analysis, and its decay was followed for up to six months. Nuclides were identified by E_α and half-life.

Recoil range is a function of both the energy and angle of separation of the dinuclear complex:

$$v_{T'} \cos \Phi_{T'} = v_T \cos \Theta_T + v_{cm} \quad (1)$$

where v_T and Φ_T are the lab velocity and recoil angle of the target-like fragment, V_T and Θ_T are its center-of-mass (c.m.) frame velocity and angle, and v_{cm} is the velocity of the center of mass. The expression on the left is a direct measure of the recoil range.

Complete fusion and massive transfer were eliminated as contributing mechanisms on the basis of the shape of the range distributions. Both should exhibit narrow distributions with a very sharp cutoff at the high-range side.[2] Figure 1 shows a typical range histogram, that of ^{252}Fm formed in the reaction of 111.6 MeV ^{18}O with ^{249}Cf. The distribution is broad with a long, high-range tail. Therefore, it was assumed that only quasi-elastic and deep inelastic transfer, or QET and DIT, contribute to these reactions.

QET is characterized by an optimal dinuclear separation energy determined by entrance-to-exit channel trajectory matching conditions and a most probable separation angle near the classical Rutherford grazing angle. In DIT, the separation energy is equal to the exit channel Coulomb barrier and, for these very fusile systems, a separation angle near 0°.

Recoil range alone is insufficient to determine both energy and angle of separation. Successive approximations using the characteristics of QET and DIT and the recoil range distributions were made to obtain an angular distribution.

Equation (1) was used to estimate the c.m. angle interval subtended by each foil, assuming separation energy at all angles equal to the exit Coulomb barrier.[3] A c.m. angular distribution was constructed from these intervals and the recoil range distribution QET and DIT components were graphically resolved, the former as a gaussian centered at a side angle, the latter as an exponential peaked at 0°. The foil-to-angle transformation was recalculated, this time with an angle-dependent separation energy; i.e., at each angle, the energy was taken to be the weighted average of the optimal and Coulomb energies, according to the relative importance of QET and DIT, respectively, at this angle. The process was repeated until the recoil range distribution predicted came no closer to that measured, and the angle intervals remained the same. Figure 2 is the set of angular distributions derived for Fm isotopes from 111.6 MeV ^{18}O + ^{249}Cf.

Except for ^{252}Fm from ^{18}O + ^{245}Cm, all observed products are from projectile stripping of one or two protons and some neutrons. Projectile-like particle measurements show that DIT is comparable in importance to QET in such reactions. However, there is no forward-peaked component in any of the derived angular distributions, except for ^{252}Fm from 111.6 MeV ^{18}O + ^{245}Cm. This can be interpreted as an effect of looking at target-like residues, which will be severely depleted by fission during de-excitation. DIT is accompanied by higher excitation than QET, particularly at low bombardment energies, so it is reasonable to expect that QET is the predominant mechanism contributing to the formation of actinide target-like residues.

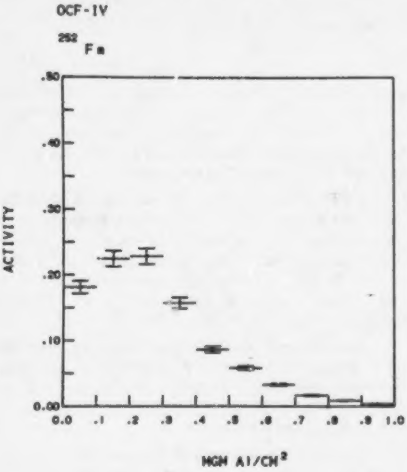

Fig. 1. Recoil range distribution of ^{252}Fm from 111.6 MeV ^{18}O + ^{249}Cf.

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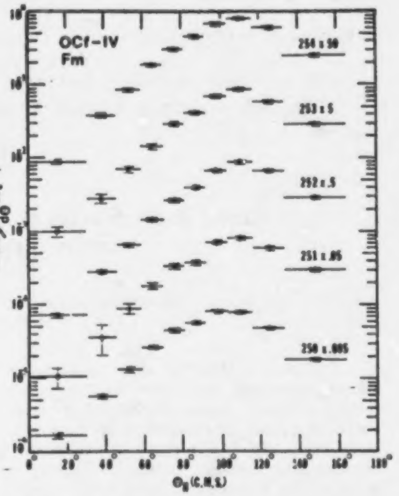

Fig. 2. Center-of-mass angular distributions of Fm isotopes for 111.6 MeV ^{18}O + ^{249}Cf derived from recoil range distributions.

XBL 826-9542

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1265

Excitation Functions for Production of Heavy Actinides from Interactions of ^{18}O with ^{248}Cm and ^{249}Cf

D. Lee, K. Moody, M. Nurmia, G.T. Seaborg, H. von Gunten, and D. Hoffman†*

Work on the production of heavy actinides by the interaction of ^{18}O and other light heavy ions on actinide targets[1] was continued in this period. We measured excitation functions for the production of isotopes of Bk through Fm in bombardments of ^{248}Cm with 97- to 122-MeV ^{18}O ions and of isotopes of Bk through No in bombardments of ^{249}Cf with 91- to 150-MeV ^{18}O ions supplied by the 88-Inch cyclotron. The isotopes of interest were assayed using radiochemical techniques. An example for excitation functions of Fm isotopes produced in the reaction of $^{18}O + ^{249}Cf$ is shown in Fig. 1. The cross sections are largest for transfer of a few nucleons and decrease rapidly with the number of transferred nucleons. They show appreciable magnitudes even below the calculated Coulomb barrier.

The experimental results were compared with calculations based on a simple model taking into account ground state Q-values for the reactions and Coulomb barriers. These comparisons show that in general about half the kinetic energy of the projectile is transferred to products that survive fission. It was also demonstrated that simple calculations of this type may be helpful in selecting projectile-target systems and optimum energies for the production of as yet unknown heavy isotopes and elements.

The present work allows a comparison of cross sections for production of isotopes of Bk through Fm from reactions of ^{18}O with ^{248}Cm and ^{249}Cf. The shapes of the mass-yield curves for both systems look rather similar. The reactions with ^{248}Cm are generally more favorable for the production of neutron-rich products, whereas those with ^{249}Cf should be used to produce lighter isotopes of an element (see Fig. 2). The cross sections and widths of the mass distributions of the same nuclear transfer, e.g., (1p,xn) or (2p,xn) are very similar for ^{18}O reactions with ^{248}Cm and ^{249}Cf.

The reactions with lighter heavy ions (e.g., ^{18}O) compares also very favorably with production cross sections obtained in reactions with very heavy projectiles (e.g, ^{238}U)[2]; however, the widths of the mass distributions are about 1 AMU narrower for the lighter projectiles.

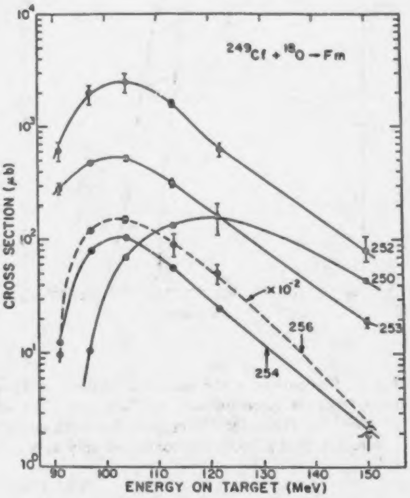

Fig. 1. Excitation functions for Fm isotopes produced in the bombardment of ^{249}Cf with ^{18}O. Points are connected only as a visual aid.

XBL 834-9099

Footnotes and References

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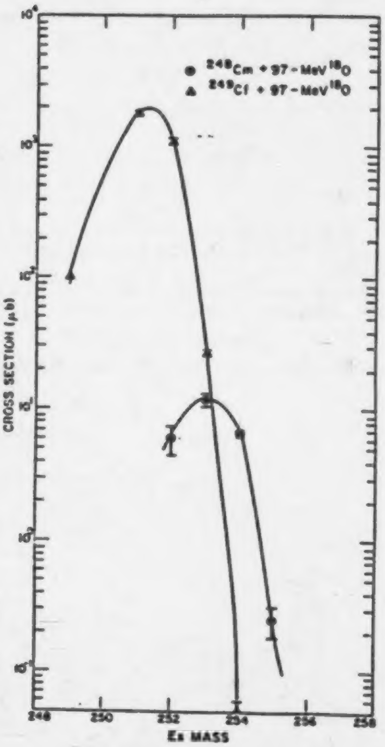

Fig. 2. Comparison of the mass distributions for Es isotopes from the bombardment of ^{248}Cm and ^{249}Cf with 97 MeV ^{18}O. (Data for ^{248}Cm from this work and Ref. 1 were averaged.) Points are connected only as a visual aid.

XBL 834-9100

PART V: INSTRUMENTATION

1. Detectors and Techniques

Ion Sources for Cyclotrons*

David J. Clark

This paper describes cyclotron ion sources for light and heavy ions. Sources of polarized ions are not included, since there are recent good reviews of this subject.

The cyclotron ion source has the responsibility for producing well collimated intense beams of various charge states of many atomic species, polarized and unpolarized. The source should have high reliability, long lifetime and quick change time. The first sources were "internal sources", designed to fit within the few centimeters of space inside the first orbit of acceleration in the central region. The approximately uniform magnetic field in this region was a great asset in producing intense ion source arcs.

With the advent of more advanced sources of heavy and polarized ions, a space of 1 m^3 or more was required for the source, so it had to be placed outside the cyclotron as an "external source". Injection systems were developed to transport the beam to the cyclotron center region, either axially or radially.

To create singly or multiply charged positive ions we must remove one or more electrons from atoms and ions. This ionization process is accomplished by electron bombardment, in which the maximum electron energy is 2–3 time the ionization potential.

For the production of high charge state ions we need bombardment with electrons of sufficient energy, E_e, and density n (electrons/cm^3) or current density J (amps/cm^2) for a sufficient time τ (sec) to reach the high charge state. Fig. 1 shows the charge/mass ratios produced for values of electron bombardment parameters $J\tau$ and $n\tau$, neglecting charge exchange and recombination.

Fig. 2 shows the operating regions of several high charge state ion sources for a range of E_e and $n\tau$ values.

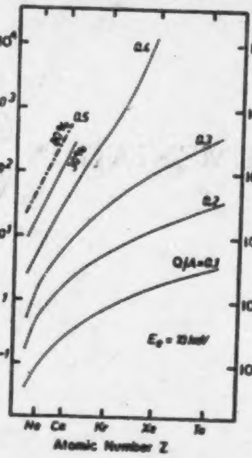

Fig. 1. Charge to mass ratio, Q/A, obtained when atom of number Z is bombarded with 10 keV electrons with ionization factor $J\tau$.

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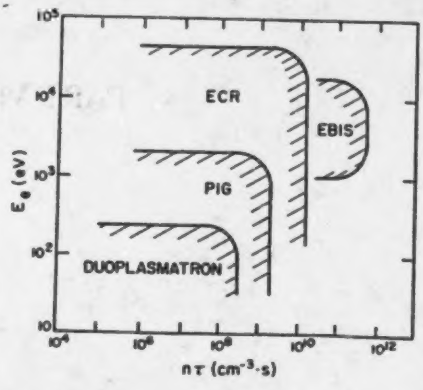

Fig. 2. Operating regions of ion sources used in present accelerators.

XBL 8211-3261

The PIG source is the standard cyclotron heavy ion source. External ECR (electron cyclotron resonance) sources are being installed on several cyclotrons to increase their energies. Although the EBIS (electron beam ion source) produces the highest charge states, it is a pulsed source with lower average beam intensity, and is not as well matched to the cyclotron. The principles and performance of these sources are described in more detail in this paper.

Footnote

*Condensed from Proc. Ninth Intl. Conf. on Cyclotrons and their Applications, Caen, France, September 7–10, 1981, pg. 231

The Plastic Ball Spectrometer: an Electronic 4π Detector with Particle Identification*

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GSI-LBL Collaboration

A concept of a 4π detector consisting of many individual ΔE-E and time-of-flight telescopes was chosen that promises fast data analysis. For the coverage of most of 4π the Plastic Ball was built, completely surrounding the target except for the very backward angles, where the beam enters the system, and the extreme forward angles. These forward angles of 0°–9° are covered with a multielement time-of-flight system (called the Plastic Wall) taking into account the large fragment velocities at forward angles. The following gives a detailed description of the whole system, as it is schematically shown in Fig. 1.

The SLAC Crystal Ball design was adopted, which is based on the geometry of an icosahedron: a 20-faced solid figure in which each face is an equilateral triangle of the same dimensions. Each face is divided into 36 triangles, resulting in the division of the surface into 720 triangles, with only 11 different two-dimensional shapes. For the Plastic Ball modifications were made in details of the entrance and exit ports. Modules in the backward cone between 160° and 180° and in the forward cone between 0° and 90° had to be omitted to allow room for the beam pipe and prevent the beam halo from hitting the detector modules.

A further modification was necessary for the region between 10° and 30° to guarantee good particle identification despite the high multiplicities expected at forward angles. This region (known as the Mall) is subdivided into 160 modules instead of the 40 in the original design and positioned at a larger radius from the target position. The central spherical cavity of the ball has a radius of 25.4 cm; the outer radius is 61.4 cm. The aforementioned surface division scheme is applied to both the outer and inner surfaces. For assembly and access to the target, the ball is divided into two half-spheres along the $\Theta = 90°$ plane. A thin sheet of 1.2 mm steel with a hole 50 cm in diameter forms the baseplate of each hemisphere.

Individual Detector Modules

Each of the 815 detector modules represents a particle identifying telescope with a ΔE and E detector using a slow and a fast scintillator read out via one photomultipler. The ΔE counter is a CaF_2(Eu) crystal with a characteristic decay time of 1 μs for the emission of the scintillation light. Unlike NaI, the CaF_2(Eu) is not hygroscopic and therefore needs no bulky canning, which would have jeopardized the system goal of a total coverage of 4π of solid angle. Each module is wrapped with only a double layer of aluminized mylar foil as an optical separator between adjacent modules.

The thickness of the ΔE CaF_2(Eu) crystal was chosen to be 4 mm with 35.6 cm as the length of the E plastic scintillator. This allowed good ΔE signals even for minimum ionizing particles and also a minimum low energy cutoff for particles stopping in the ΔE counter. To obtain clean proton spectra up to 200 MeV, the detector length was chosen to stop 240 MeV protons. This length represents a physical upper limit for particle identification for stopped particles due to the onset of reaction losses.

The readout of the ΔE-E module is done via a conically shaped lightguide (lucite), which couples to a 2-inch, 10-stage photomultiplier. The phototube was

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APPENDIX II Thesis Abstracts

Nuclear Reaction Studies Via the Observation of Unbound Outgoing Systems

Alden Newell Bice

The mechanisms involved in the production of fast α-particles in ^{12}C induced reactions have been investigated for the $^{12}C + ^{208}Pb$ system at bombarding energies of $E(^{12}C) = 132$, 187 and 230 MeV. Absolute cross sections have been determined for the reactions $^{208}Pb(^{12}C, ^{8}Be\ (g.s.))$, $^{208}Pb(^{12}C, ^{8}Be\ (2.94\ MeV))$ and $^{208}Pb\ (\ ^{12}C\ ,\ ^{12}C^{*} \rightarrow \alpha + ^{8}Be\ )$ by double and triple coincidence measurements of the sequential decay α-particles. Inclusive α-particle production cross sections were also measured at $E(^{12}C) = 187$ MeV for comparison. It is found that the simple inelastic scattering process $(\ ^{12}C\ ,\ ^{12}C^{*} \rightarrow \alpha + ^{8}Be\ )$ does not contribute significantly to the production of fast α-particles but that the production of ^{8}Be nuclei by projectile fragmentation is an important source of α-particles. At the highest bombarding energy investigated (19 MeV/A) it appears that the $^{12}C \rightarrow 3\alpha$ fragmentation reaction becomes more prominent at the expense of the $^{12}C \rightarrow \alpha + ^{8}Be$ fragmentation channel. Although qualitatively these results are not in disagreement with the incomplete fusion model predictions of Wilczynski it is concluded that projectile spectroscopic properties and/or final state interactions are important in fragmentation reactions for these bombarding energies.

In a kinematically complete experiment the direct and the sequential breakup channels of 10 MeV/A ^{7}Li projectiles have been investigated with ^{12}C and ^{208}Pb targets. By appropriate arrangement of detector telescopes it was possible to define a kinematical window which allowed for the unambiguous observation of both the direct (to the α-t continuum) and the sequential components of a heavy-ion projectile breakup reaction. A semiclassical Monte Carlo type projectile breakup calculation was constructed which qualitatively reproduced the measured α-t coincidence cross section as a function of the laboratory angle.

Zero Field Spin Relaxation of the Positive Muon in Copper

Carl William Clawson

The spin relaxation of the μ^+ in high purity single crystal and polycrystalline copper has been measured at temperatures between 0.5 K and 5.2 K by the zero-field μ^+ SR technique. In both types of sample the experiments show a temperature independent dipolar width $\Delta_z = 0.389 \pm 0.003\ \mu s^{-1}$ and a hopping rate decreasing from $\sim 0.05\ \mu s^{-1}$ at 0.5 K to $\sim 0.05\ \mu s^{-1}$ above 5 K. This is the first direct proof of a dynamic effect in the low temperature μ^+ spin relaxation in copper.

The relationship between the zero-field and transverse-field dipolar widths is discussed, and the measured zero-field width is found to be ~10% larger than expected based on the known transverse-field widths. A new μ^+SR spectrometer has been constructed and used in this work. The spectrometer and the associated beam lines and data acquisition facilities are discussed.

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Observation of Anomalous Reaction Mean Free Paths of Nuclear Projectile Fragments in Research Emulsion from 2 AGeV Heavy Ion Collisions

Yasha J. Karant

From an analysis of 1460 projectile fragment collisions in nuclear research emulsion exposed to 2.1 AGeV ^{16}O and 1.9 AGeV ^{56}Fe at the Bevalac, evidence is presented for the existence of an anomalously short interaction mean free path of projectile fragments for the first several cm after emission. The result is significant to beyond the 3 standard deviation confidence level.

Recoil Range Studies of Heavy Products of Multinucleon Transfer from ^{18}O to ^{245}Cm and ^{249}Cf

Rose Marie McFarland

Recoil range distributions were measured for alpha and spontaneous fission activities made in the bombardment of ^{245}Cm and ^{249}Cf with ^{18}O from 6.20 MeV/nucleon down to the interaction barrier. The shape of the distributions indicates that transfers of up to four protons take place via a combination of quasi-elastic (QET) and deep inelastic (DIT) mechanisms, rather than complete fusion-de-excitation (CF) or massive transfer (MT). Angular distributions constructed from recoil range distributions, assuming QET/DIT, indicate that the QET component contributes more significantly to the heavy product residue cross section than the DIT, even though primary cross sections are expected to be higher for DIT than for QET. This may be explained qualitatively as a result of the high excitation energies associated wih DIT; the very negative Q_{gg} of projectile stripping for these systems combined with the lower expected optimal Q_{rxn} of QET compared to DIT can give QET products comparatively low excitation.

Meson Production in Relativistic Heavy Ion Collisions

Stephen R. Schnetzer

We have measured the inclusive K^+ production cross sections at angles from 15° to 80° in collisions of protons (2.1 GeV) and deuterons (2.1 GeV/amu) on NaF and Pb, and Ne (2.1 GeV/amu) on C, NaF, KCl, Cu and Pb. The kaons were identified by measuring the time of flight and the momentum in a magnetic spectrometer, and by detecting the particles from the kaon decays in a lead-glass Čerenkov counter. The momentum range of the detected kaons extended from 350 MeV/c to 750 MeV/c. The multiplicity of each event was measured bu a set of scintillation counter telescopes which were situated around the target.

The differential cross section of the kaons falls off exponentially with center of mass energy in the nucleon-nucleon center of mass frame. In addition, the angular distribution of the kaons is nearly isotropic in this frame even for p-NaF and Ne-Pb collisions. The data are compared with a row-on-row model and a thermal model. Neither are able to explain all features of the data. The row-on-row model does not reproduce the near-isotropy in the nucleon-nucleon frame, and the

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thermal model overpredicts the kaon yield by a factor of approximately twenty.

Analysis of the A-dependence shows that the increase in the cross section for kaon production between Ne-NaF and Ne-Pb collisions is greater than that between d-NaF and d-Pb. This may be an indication of a collective effect.

In Ne-Pb collisions the associated multiplicity is approximately 10% higher when a kaon is detected in the spectrometer than when a proton or pion is detected. This indicates that the kaons may come from more central collisions.

Light Particle Emission as A Probe of the Rotational Degrees of Freedom in Deep-Inelastic Reactions

Lee G. Sobotka

The emission of alpha particles in coincidence with the most deeply inelastic heavy-ion reactions has been studied for ^{181}Ta + ^{165}Ho at 1354 MeV laboratory energy and ^{nat}Ag + ^{84}Kr at 664 MeV. Alpha particle energy spectra and angular distributions, in coincidence with a projectile-like fragment, were acquired both in the reaction plane and out of the reaction plane at a fixed in-plane angle.

The in-plane data for both systems are employed to show that the bulk of the alpha particles in coincidence with the deep-inelastic exit channel can be explained by evaporation from the fully accelerated fragments. Average velocity diagrams, α-particle energy spectra as a function of angle in several rest frames, and α-particle angular distributions are presented.

The out-of-plane alpha particle angular distributions and the gamma-ray multiplicities are used to study the transfer and partitioning of angular momentum between the two fragments. For the ^{nat}Ag + ^{84}Kr system individual fragment spins are extracted from the alpha particle angular distributions as a function of mass asymmetry while the sum of the fragment spins is derived from the gamma-ray multiplicities. These data, together with the fragment kinetic energies, are consistent with rigid rotation of an intermediate complex consisting of two substantially deformed spheroids in near proximity. These data also indicate that some angular momentum fractionation exists at the largest asymmetries examined. Out-of-plane alpha particle distributions, gamma-ray multiplicities, fragment spins as well as the formalism for the spin evaluation at various levels of sophistication are presented.

Observation of New Spontaneous Fission Activities from Elements 100 to 105

Lawrence Patrick Somerville

Several new Spontaneous Fission (SF) activities have been found. Their half-lives and production cross sections in several reactions bave been measured by collecting and transporting recoils at known speed past mica track detectors. No definite identification could be made for any of the new SF activities; however, half-lives and possible assignments to element-104 isotopes consistent with several cross bombardments include ^{257}Rf(3.8 s, 14% SF), ^{258}Rf(13 ms), ^{259}Rf(~3 s, 8% SF), ^{260}Rf(~20 ms), and ^{262}Rf(~50 ms). The 80-ms SF activity claimed by the Dubna group for the discovery of element 104 (^{260}104) was not observed. A difficulty exists in the interpretation that ^{260}Rf is a ~20-ms activity: in order to be correct, for example, the SF activities with half-lives between 14 and 24 ms produced in the reactions 109- to 119 MeV ^{18}O + ^{248}Cm , 88- to 100-MeV ^{15}N + ^{249}Bk, and 96- MeV ^{18}O + ^{249}Cf must be other nuclides due to ther large production cross sections, or the cross sections for production of ^{260}Rf must be enhanced by unknown mechan-

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isms. Based on calculated total production cross sections a possible ~1% electron-capture branch in ^{258}Lr(4.5 s) to the SF emitter ^{258}No(1.2ms) and an upper limit of 0.05% for SF branching in ^{254}No(55 s) were determined. Other measured half-lives from unknown nuclides produced in respective reactions include ~1.6 s (^{18}O + ^{248}Cm), indications of a ~47-s SF activity (75-MeV ^{12}C+^{249}Cf), and two or more SF activities with $3s \leq T_{1/2} \leq 60s$ (^{18}O+^{249}Bk). The most exciting conclusion of this work is that if the tentative assignments to even-even element-104 isotopes are correct, there would be a sudden change in the SF half-life systematics at element 104 which has been predicted theoretically by Randrup et al. and Baran et al. and attributed to the disappearance of the second hump of the double-humped fission barrier. This disappearance of the second barrier also explains the tentative low hindrance factors compared to lighter elements for SF of the odd-mass isotopes ^{257}Rf (~4x10^{3}) and ^{259}Rf (~2x10^{3}). On the basis of recent odd-mass alpha-decay energy data, the 152-neutron sub-shell effect is probably weaker for element 104 than for element 102, confirming predictions of Randrup et al., and not strong enough to significanatly alter the SF half-life predictions. This weakening sub-shell effect is in contrast to the continuing strong effect assumed in the Ghiorso half-life systematics. The possibilities of enhanced stability against SF with 157 neutrons for ^{261}Rf(65 s) and theoretical arguments concerning the SF-mass distribution for element-104 nuclei are discussed.

Coulomb Effects on Pions Produced in Heavy Ion Reactions

John Peter Sullivan

Double differential cross sections for the production of π^+ and π^- near the velocity of the incident beam for pion lab angles less than 40 degrees are presented. The experimental apparatus and the techniques are discussed. Beams of ^{20}Ne with E/A from 80 to 655 MeV and ^{40}Ar with E/A = 535 MeV incident on Be, C, NaF, KCl, Cu, and U targets were used. A sharp peak in the π^- spectrum and a depression in the π^+ spectrum were observed at zero degrees near the incident beam velocity. The effect is explained in terms of Coulomb interactions between the pions and fragments of the incident beam. Least squares fits to the data using the Coulomb correction formulas of Gyulassy and Kauffmann and an effective projectile fragment charge are made. The relationship between these data and previously measured pion production and projectile fragmentation data is discussed. The data are also compared to some theoretical models. A simple expression is given for the differential cross section as a function of the projectile mass, target mass, and beam energy.

A (p,2p) Study of High Momentum Components at 2.1 GeV

Robert Neil Treuhaft

A (p,2p) experiment designed to isolate interactions with small numbers of fast nuclear constituents is described. Special attention is paid to the experimental manifestation and description of a correlated pair of nucleons in the nucleus. Phase space calculations are presented for the proton-pair three-body final state and for final states with larger numbers of particles. The Two Armed Spectrometer System (TASS) is described in detail. The data suggest the possibility of isolating an interaction with one or two nucleons in the nucleus which may have momenta far in excess of those described in a Fermi gas model.

APPENDIX II Thesis Abstracts

Decay Studies of the Highly Neutron-Deficient Indium Isotopes

Jan Marc Wouters

An extension of the experimentally known nuclidic mass surface to nuclei far from the region of beta-stabiliy is of fundamental interest in providing a better determination of the input parameters from the various nuclear mass formulae, allowing a more accurate prediction of the ultimate limits of nuclear stability. In addition, a study of the shape of the mass surface in the vicinity of the doubly-closed nuclide ^{100}Sn provides initial information on the behavior of the shell closure to be expected when Z=N=50. Experiments measuring the decay energies of $^{103\text{-}105}$In by β-endpoint measurements are described with special attention focused on the development of a plastic scintillator β-telescope coupled to the on-line mass separator RAMA (Recoil Atom Mass Analyzer). Attempts to measure the β-endpoint energy of ^{102}In is also briefly described.

The experimentally determined decay energies and derived masses for $^{103\text{-}105}$In are compared with the predictions of different mass models to identify which models are more successful in this region. Furthermore, the inclusion in these comparisons of the available data on the neutron-rich indium nuclei permits a systematic study of their ground state mass behavior as a function of the neutron number between the shell closures at N=50 and N=82. These analyses indicate that the binding energy of ^{103}In is 1 MeV larger than predicted by the majority of the mass models.

An examination of the Q_{EC} surface and the single- and two-neutron separation energies in the vicinity of $^{103\text{-}105}$In is also performed to investigate further the above deviation and other possible systematic variations in the mass surface in a model-independent way. The ^{103}In Q_{EC} and the ^{105}In s_{2n} are shown to diverge seriously from systematics. Ascribing these effects to the mutual support of shell closures, which would cause a strengthening of the proton binding energy with decreasing neutron number, requires additional investigation. Interestingly, the neighboring even cadmium 2^+ and 4^+ excited state systematics indicate that these nuclei are becoming more spherical with decreasing neutron number as expected near a double shell closure.

Two-Pion Correlations in Heavy Ion Collisions

William Allen Zajc

An application of intensity interferometry to relativistic heavy ion collisions is reported. Specifically, the correlation between two like-charged pions is used to study the reactions $Ar+KCl \rightarrow 2\pi^{\pm}+X$ and $Ne+NaF \rightarrow 2\pi^{-}+X$. Source sizes are obtained that are consistent with a simple geometric interpretation. Lifetimes are less well determined but are indicative of a faster pion production process than predicted by Monte Carlo cascade calculations. There appears to be a substantial coherent component of the pion source, although measurement is complicated by the presence of final state interactions. Additionally, the generation of spectra of uncorrellated events is discussed. In particular, the influence of the correlation function on the background spectrum is analyzed, and a prescription for removal of this influence is given. A formulation to describe the statistical errors in the background is also presented.

Finally, drawing from the available literature, a self-contained introduction to Bose-Einstein correlations and the Hanbury-Brown-Twiss effect is provided, with an emphasis on points of contact between classical and quantum mechanical descriptions.